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ALCOA

FEASIBILITY STUDY FOR DEVELOPMENT OF AN ALUMINUM ALLOY FOR FABRICATION OF SMALL ARMS CARTRIDGE CASES

Contract No. DAAA25-68-C0771

issued by

Frankford Arsenal
Philadelphia, Pennsylvania

FINAL REPORT

for the period

June 28, 1968 to October 28, 1969

Alcoa Research Laboratories

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November 24, 1969

ALUMINUM COMPANY OF AMERICA
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FOREWORD

This report was prepared by the Aluminum Company of America under Contract Number DAAA25-68-C0771 issued by the U. S. Army, Frankford Arsenal. The contract was administered by Mr. Harry J. Krusch, Contracting Officer, and the Technical Supervisor was Mr. Marvin Rosenbaum.

Mr. H. Y. Hunsicker was the Alcoa Project Co-ordinator. The author would also like to acknowledge the major contributions to this work made by the following Alcoa Research Laboratories personnel: Messrs. M. S. Hunter and D. L. Robinson for the electron microscopic investigations of structure and fracture mode and Mr. J. D. Walsh for the corrosion studies.

SYNOPSIS

Five experimental, low impurity content aluminum alloys were cast as large commercial-size ingots and fabricated in a sheet rolling mill to starting stock gauges for small arms cartridge case manufacture. Samples were laboratory rolled to .063 inch stock for evaluation of characteristics such as tensile properties, fracture toughness, resistance to corrosion and stress corrosion, temperature stability and quench sensitivity.

Although none of the alloys achieved the target strength-toughness criteria of both a tear/yield strength ratio of 1.5 and a yield strength of 80 ksi, two compositions were superior to conventional alloys in this respect. These were nominally Al-5 Zn-2.4 Mg-1.2 Cu-.15 Cr (MA07) and Al-5.9 Zn-2.4 Cu-2.2 Mg-.3 Mn (MA08).

One strain-hardenable alloy, Al-7.5 Mg-.1 Mn-.1 Cr (MA09) was included in the evaluation and displayed good notch toughness and moderate resistance to crack growth but at a relatively low strength level compared to the heat-treatable alloys.

Electron metallography and fractography showed fracture toughness to depend upon the relative proportions of fracture path that were intergranular or transgranular and, hence, upon relative strengths of grain interiors and boundaries. The effect of second-phase constituent particles upon fracture toughness was not discernible at the low insoluble element level of these alloys.

INTRODUCTION

The use of aluminum for cartridge cases is attractive from the standpoints of weight savings, conservation of copper and possibly of cost. The service conditions, however, are severe for aluminum alloys since internal pressures of more than 50,000 psi can be reached in one millisecond after firing and any discontinuities in the case are subject to erosion by high-temperature, high-velocity propellant gases. In addition to high strength and fracture toughness to assure case integrity during firing, resistance to stress-corrosion cracking must be considered since the assembly of case and projectile may result in residual stresses in a portion of the cartridge case.

Work under Contract DAAA25-68-C0771 covered the evaluation of five aluminum alloys in regard to their suitability for small arms cartridge cases. Target requirements for this end use were established by Frankford Arsenal to include the following:

(1) Yield strength of 80 ksi

(2) Tear strength/yield strength ratio of 1.5

(3) Good resistance to general corrosion and stress-corrosion cracking

(4) Stability of properties from -70 to 165 F.

(5) Adequate formability for present cartridge case equipment and methods.

(6) Thermal treatments not unduly complicated or expensive. Alloy not quench sensitive in thicknesses up to .500 inch.

Previous comparisons of the fracture toughness of various types of aluminum alloys have shown the 7000 series (Al-Zn-Mg and Al-Zn-Mg-Cu) to have the highest level of tear resistance for a given level of strength[1]. Unpublished work at Alcoa Research Laboratories further showed that, at the highest strength levels, Al-Zn-Mg-Cu alloys were superior to the Cu-free Al-Zn-Mg alloys. The stress-corrosion cracking resistance of the Al-Zn-Mg-Cu alloys is also superior. It was further found that at a specific strength level the tear resistance of an alloy in T6 temper was greater than that of a more highly alloyed composition in an overaged T7 type temper.

Three compositions designated MA05, MA06, and MA07 were selected to represent a series of increasing Zn + Mg contents with Zn/Mg ratios of 2 to 2.5 that were expected to develop the highest strengths for a given total of these two elements. Copper contents of these alloys were maintained in the range 1.1 to 1.4%, and chromium contents were 0.13 to 0.17%. The MA05 alloy level was selected to obtain in the T6 temper an 80 ksi yield strength, MA06 for a maximum tear/yield strength ratio and MA07 for an intermediate level of both of these criteria.

Another similar composition which has exhibited good stress-corrosion cracking resistance at high strength levels

in other experimental programs was included for evaluation; this alloy, designated MA08, has a higher Cu and lower Mg content and substitutes Mn for Cr as an ancillary alloying addition.

Finally, a non-heat treatable alloy was chosen for evaluation to determine to what extent the fracture toughness and strength levels developed by the large amount of cold work anticipated in cartridge case manufacture would meet the target criteria. This alloy, MA09, was to contain 7.5 Mg, which is considerably more than the Mg content of any present commercial Al-Mg wrought alloy.

High purity refined aluminum was used in producing the ingots to minimize the insoluble constituents introduced by Fe and Si impurities. The compositions of the alloys are listed in Table 1.

PROCEDURE

Commercial size ingots were cast at Alcoa Technical Center for this program. Three 8" x 38" x 130" ingots were cast in MA09 and one 12" x 38" x 130" in each of the other alloys. All were cast by the direct water-chill method.

Soundness of the ingots was established by ultrasonic inspection and by macroscopic examination of a slice sawed from the head end of each ingot after cropping an 8 inch length. The ingot slices were also subjected to dye penetrant inspection and found satisfactory in this respect.

The ingots were fabricated into sheet at Alcoa's Tennessee Operations by the practices listed in Table 2.

Shipments of the .150 and .187 inch annealed-temper sheet were made to Frankford Arsenal and to Alcoa Research Laboratories.

Tensile properties, strain ratio (R) and strain hardening coefficient (n) values, and hardness were determined for the as-received stock which was then flat-rolled to .063 inch at which thickness solution and precipitation treatments were applied for subsequent testing in the T6 type tempers. Solution heat treating temperatures were the maximum obtainable without encountering eutectic melting as established from thermal analyses and confirmed by metallographic examination. The solution heat treatments used subsequently for .063 inch sheet specimens throughout this program were

MA05	MA06	MA07	MA08
1 hr at 890 F	1 hr at 960 F	1 hr at 960 F	1 hr at 910 F

With the exception of tests for quench sensitivity, all specimens were quenched in cold (room temperature) water.

Isothermal precipitation treatments at 250 F and 275 F for one to 36 hours for the four heat-treatable alloys (plus 300 F precipitation treatments for MA08) were evaluated by determining tensile properties. Precipitation treatments by step aging were also investigated using a first step of 3 hours at 250 F (also 3 hours at 275 F for MA08). All heating rates to the initial precipitation temperature were at a uniform 90 F/hour, and a four-day minimum prior room temperature aging interval was observed.

A brief evaluation of the effect of heating rate to the initial precipitation temperature in step precipitation treatments was obtained by employing two different heating rates to reach the initial temperature immediately after solution heat treatment and quencning.

A similar investigation was conducted to determine the effect on strength of the room temperature aging interval between solution heat treatment and elevated temperature precipitation treatments. A heating rate of 90 F/hour to initial precipitation temperature was employed both for samples treated immediately after quenching and those held four days at rcom temperature before elevated-temperature precipitation was started.

Employing the precipitation cycles which developed maximum strengths, sheet samples in the T6 type tempers (F for MA09) were obtained to test for tear resistance, stress-corrosion resistance, and temperature stability.

Resistances to corrosion and to stress-corrosion cracking were evaluated by 12 weeks exposure to alternate immersion in 3.5% NaCl solution at ambient temperature and humidity. Stressed preformed specimens and transverse tensile specimens stressed to 50 and 75% of the yield strength were employed in these tests.

Stability of properties after extensive storage at high and low temperatures was determined by holding sheet samples for 30 days in contact with dry ice (-110 F) or for 30 days at 165 F. Tensile and tear tests were then performed at room temperature.

Quench sensitivity of the four heat-treatable alloys was evaluated by cold rolling .500 inch, .250 inch, and .125 inch thick samples from .750 inch hot mill slabs for heat treatment together with samples from .187 inch annealed-temper stock and from .063 inch as-rolled sheet. Panels 12 inches square of these several thicknesses were quenched into both cold and boiling water baths and after precipitation treatment were tested for tensile properties.

Cold rolled MA09-F samples were subjected to thermal treatments of 1-12 hours at 425-550 F to determine the maximum thermal stress relief temperature that could be applied without encountering recrystallization. Pinhole x-ray diffraction procedures and tensile property determinations were employed for this.

RESULTS

Precipitation Heat Treating Curves

Tables 3-6 contain tensile test and electrical conductivity data for MA05, MA06, MA07, and MA08 as a function of precipitation heat treatments. Figures 1-4 contain yield strength curves and Figures 5-8 electrical conductivity curves plotted from these data.

It will be noted that MA05, MA06, and MA07, which are the same type of alloy varying only in alloy content, had very similar precipitation hardening curves; in isothermal aging, peak yield strengths were reached after 36 hours at either 250 or 275 F or in 16-24 hours at 275 F. Their step-aging

curves were also similar, although the time to reach peak strengths can be seen to decrease with increasing alloy content.

MA08 differed from the other alloys in developing higher levels of strength (within 36 hours) by isothermal precipitation at 275 F or 300 F than at 250 F. In step precipitation treatments, the time to reach peak strengths for MA08 was considerably longer than for MA05, which was of about the same strength level. It was indicated that first-step aging at 275 F shortened the time for the second step to achieve peak strength, but did not increase peak strength.

Effect of Heating Rate to Initial Precipitation Temperature

As the following Table 7 shows, fast initial heating rates decreased the strength of the more dilute alloys, MA06 and MA07, but not that of the higher strength alloys.

TABLE 7: Effect of Heating Rate to Initial Precipitation Temperature Upon Tensile Properties

Alloy	Heating Rate to First Step °F/hour	Precipitation Treatment	Tensile Strength ksi	Yield Strength ksi	Elongation % in 2"
MA05	90	3/250 + 5/325 F	82.4	76.9	11.0
	1800	3/250 + 5/325 F	82.4	77.1	10.2
MA06	90	3/250 + 5/340 F	70.1	61.4	12.5
	1800	3/250 + 5/340 F	63.9	50.4	12.2
MA07	90	3/250 + 5/340 F	72.9	66.9	6.5
	1800	3/250 + 5/340 F	72.1	64.8	11.5
MA08	90	3/250 + 9/325 F	83.8	78.3	10.0
	1800	3/250 + 9/325 F	83.6	78.2	9.5

Effect of Room Temperature Aging Interval

The effects of four-day compared to no room temperature aging prior to elevated temperature precipitation are seen in the following Table 8. Only in the most dilute alloy, MA06, was any benefit evident from aging at elevated temperatures immediately after solution heat treatment and quenching.

TABLE 8: Effect of Room Temperature Aging Interval Between Solution Heat Treatment and Elevated Temperature Precipitation Treatment

Alloy	Room Temp. Aging Period	Precipitation Treatment	Tensile Strength ksi	Yield Strength ksi	Elongation % in 2"
MA05	0	3/250 + 5/325 F	82.4	76.9	11.0
	4 days	3/250 + 5/325 F	83.4	76.8	11.0
MA06	0	3/250 + 5/340 F	70.1	61.4	12.5
	4 days	3/250 + 5/340 F	68.9	59.4	11.5
MA07	0	3/250 + 5/340 F	72.9	66.9	6.5
	4 days	3/250 + 5/340 F	74.9	67.8	11.5
MA08	0	3/250 + 9/325 F	83.8	78.3	10.0
	4 days	3/250 + 9/325 F	84.8	78.2	10.0

Tear Resistance

The Kahn-type tear testing procedure, as described elsewhere (1,2,3), reports results as tear strength/yield strength ratio (tear/Y.S.), which is a measure of notch toughness, and as unit propagation energy (UPE), which is a measure of the resistance to crack growth. The tear and tensile test results for the five alloys are contained in Table 9.

It will be seen that the anticipated strength and fracture toughness levels for the three Al-Zn-Mg-Cu-Cr alloys in the T6-type temper were obtained; MA05 yield strengths approached

80 ksi, the tear/Y.S. of MA06 was above 1.5 and MA07 had tear/Y.S. values over 1.4 at yield strengths of 67-68 ksi. Also of significance is a comparison of the two highest strength alloys, MA05 and MA08; the latter displayed higher tear/Y.S. and UPE values for the same yield strength level. This is better shown in Figure 9 where tear/Y.S. values are plotted against yield strength; it can also be seen that the difference in notch toughness between the two alloys decreased considerably as the yield strength approached 80 ksi.

Figures 10 and 11 are the same type of plot of transverse tear/Y.S. and UPE, respectively, versus yield strength covering all of the alloys in this program. Kaufman and Holt's data for commercial 7075-T6, 7079-T6 and 7178-T6 sheet are also plotted for comparison[1].

<u>Resistance to Corrosion and Stress-Corrosion Cracking</u>

The results of 12 weeks exposure of the five alloys to 3 1/2% NaCl alternate immersion corrosion testing are listed in Table 10 together with results for a 7075-T6 stock sample included for comparison.

All materials were highly resistant to stress-corrosion cracking in the .063 inch sheet thickness and of the same order of corrosion resistance as the 7075-T6 sheet. Among the four heat-treatable alloys, MA05 showed slightly greater losses in strength when exposed in the stressed condition than did the other three alloys which were about equal in this respect. The Al-7.5 Mg alloy, MA09, showed the excellent resistance to

aqueous chloride solutions that is typical of this type of alloy.

Temperature Stability

The original tensile and tear properties for all five alloys are compared with those after 30 days storage at -110 F or at 165 F in Table 11. The cold storage had no effect on properties with the possible exception of MA08; here a slight decrease in fracture toughness was noted.

The 165 F storage generally resulted in some additional precipitation hardening in the four heat-treatable alloys; tensile and yield strengths were increased slightly and fracture toughness parameters were correspondingly decreased by a small amount. In the case of as-rolled MA09-F, storage at 165 F caused a considerable degree of recovery; strengths were decreased substantially while elongation and fracture toughness values increased markedly.

Formability

Tensile and hardness test results for the .150 inch and .187 inch annealed-temper stock supplied to Frankford Arsenal and ARL are listed in Table 12. As would be expected, the strength and hardness of the Al-7.5 Mg alloy, MA09-0, were much higher than for the other materials; its strain ratio ($\bar{R}$) and strain-hardening coefficient ($\bar{n}$) values, however, were high indicating drawability should be good.

The hardness values for the other four alloys were within or only slightly above the 55-65 Rockwell 15T range reported

by Frankford Arsenal as typical for their present fabricating practice using 7075-0 stock. Hardness and strength varied directly and $\bar{n}$ values inversely in accordance with the alloy content of the materials.

Final judgement as to the formability of these alloys will depend upon Frankford Arsenal's experience with them in manufacture of cartridge cases.

Some age hardening tendencies in MA08-0 were noted even though a slow cool and low-temperature stabilize treatment were prescribed as part of the annealing cycle. As discussed below, this alloy also showed a very low degree of quench sensitivity.

Quench Sensitivity

Table 13 contains the tensile test results for transverse specimens of various thicknesses quenched in cold or boiling water; the yield strengths are plotted against specimen thickness in Figure 12. It will be seen that none of the alloys was sensitive to the quenching rate variations encountered in thicknesses to .500 inch when quenching was into cold (room temperature) water.

Boiling water quenching disclosed some differences between the alloys; in the Al-Zn-Mg-Cu-Cr types, boiling water quench sensitivity varied with the alloy content (Zn + Mg) and was very pronounced in the most highly alloyed material, MA05. In contrast, MA08, the equally strong Al-Zn-Cu-Mg alloy with Mn instead of Cr, showed almost no strength variation with

thickness when quenched into boiling water or into cold water.

Stress Relief Temperatures for MA09-F

The effects of 425 to 550 F stress relief treatments on the yield strength of as-rolled MA09 sheet are shown in Figure 13 plotted from data listed in Table 14. It was found that treatments at 500 F or below did not produce a degree of recrystallization detectable by x-ray diffraction analysis.

Relationships of Structure to Strength and Toughness

From the results of the tests described in previous sections, the five alloys in this program met most of the Frankford Arsenal criteria for a cartridge case alloy except that none achieved both a tear/Y.S. ratio of 1.5 and a yield strength of 80 ksi. It was considered desirable, therefore, to investigate the relationship of the structures of the heat-treatable alloys to their strength and toughness characteristics.

Figures 14-18 are 500X photomicrographs of the longitudinal (YZ) plane perpendicular to the rolling plane for the five alloys--after solution heat treatment and isothermal precipitation for the heat-treatable alloys and in the as-rolled condition for MA09. Figures 14-16 for MA05, MA06, and MA07 show small amounts of equilibrium second-phase particles corresponding to the low (.04-.06 Si + Fe) insoluble element contents of these alloys (Table 1) as an electron microprobe analysis showed them to be Al_7Cu_2Fe. In this text, second-phase particles is the

term applied to those particles resolved by optical microscopy and not to precipitate or dispersoid particles requiring electron microscopy.

In Figure 17, the microstructure of MA08 shows a distinctly larger number and higher volume fraction of equilibrium second-phase particles corresponding to its .09 Si + Fe content. These particles were also identified by electron microprobe and x-ray Guinier analyses as Al_7Cu_2Fe but with Mn replacing some of the Fe. In spite of its having a greater volume fraction of these second-phase particles, the fracture toughness of MA08 was significantly greater than that of MA05 (Figure 14) of equivalent strength.

All of the heat-treatable alloys had fully recrystallized structures as verified by x-ray diffraction analysis. The grain size of all four alloys was fine; MA08 has the finest grain size (ASTM No. 9) and MA06 the coarsest (ASTM No. 8.5) as also determined by x-ray diffraction. MA08 showed a more nearly equiaxed grain structure than did the Cr-bearing alloys. Figure 18 (MA09-F) illustrates the typical structure of highly cold-worked Al-Mg alloys in which a portion of the Mg is precipitated in the form of Al_3Mg_2 phase.

Figures 19-22 are 50,000X thin film transmission electron micrographs of MA05, MA06, MA07 and MA08, respectively, after solution heat treatment and isothermal precipitation treatments. Of interest here is a comparison of dispersoid particle (high temperature precipitates of Cr or Mn-bearing

phases) size and distribution. Of the three Cr-containing alloys, MA05 (Figure 19) showed about the same volume fraction but considerably smaller and more numerous E phase ($Al_{12}Mg_2Cr$) dispersoid particles than MA06 and MA07 (Figures 20 and 21). This difference in size was considered primarily a result of the difference in solution temperatures employed for the alloys. The higher alloy content of MA05 necessitated use of a lower solution temperature. Precipitation of E phase occurs primarily at solution temperatures which are effectively precipitation temperatures for the supersaturated Cr solid solution, and the lower solution temperature for MA05 would be expected to develop a finer precipitate.

In MA08 (Figure 22), the Mn dispersoid particles ($Al_{20}Cu_2Mn_3$) were of about the same size as the E phase particles present in MA06 and MA07. The apparent volume percent of Mn-bearing dispersoid was somewhat lower than that of the E phase dispersoid in the Cr-containing alloys.

In these 50,000X micrographs the strengthening G-P zone structure is apparent as a very fine scale mottling of the matrix. Grain boundary precipitate particles of M phase generally ranging to 500 Å in maximum dimension are apparent on tilt boundaries in all cases. In MA05 (Figure 19) several much larger grain boundary precipitate particles are also evident at the triple point as well as along the grain boundary proceeding to the right.

Figures 23-26 are electron micrographs of the same alloys but at 100,000X; the (a) structures are those of isothermally

aged material (24-36 hours at 275 F) and the (b) structures after step-aging (3 hours at 250 F plus 5-9 hours at 325 or 340 F). Differences in zone size among alloys for the same type of precipitation hardening treatment were apparent. The higher alloy content (and higher strength) MA05 and MA08 (Figures 23 and 26) exhibited the smallest zones, and the lowest strength and most dilute alloy, MA06 (Figu › 24) the largest. Step-aging produced appreciably larger zon sizes than did isothermal aging for each alloy and the differences between alloys were preserved. Despite the significant differences in zone size and electrical conductivity (Table 9) produced by the two types of precipitation treatments for a given alloy, the corresponding differences in strength and fracture toughness levels were relatively minor.

Grain boundary precipitates were apparent in all four alloys. Some differences among the alloys in apparent continuity of the grain boundary precipitate are indicated by the micrographs. However, it must be kept in mind that the morphology, density and distribution of grain boundary precipitate particles vary from one boundary to another depending upon the relative orientations of the adjacent grains. The small field shown, selected as representative in each case, does not show all the grain boundary conditions present in each composition. In general, the MA05 sample (Figure 23) appeared to have the least continuous grain boundary precipitate, while MA08 (Figure 2') had the finest and most nearly continuous grain boundary precipitate. MA06, the most dilute of the Al-Zn-Mg-Cu alloys, had the widest

precipitate-free zone adjacent to grain boundaries (Figure 24).

While yield strength differences among these alloys correlated in the expected way with zone size, there were no prominent structural differences to which the large differences in tear characteristics could be clearly related--especially the nearly 10 to 1 UPE differences between MA06 and MA07 at the one extreme and MA05 at the other with MA08 somewhat intermediate.

To investigate further the modes of fracture, scanning and replica transmission electron micrographs of the fracture surfaces were made. Figure 27 is an SEM fractograph of an MA05-T6 transverse tear specimen having low fracture toughness (UPE of 150 in-lb/in^2, tear/Y.S. of .95) and high strength (yield strength of 78.1 ksi). The fracture path for this specimen was predominantly intergranular, occurring by shear at grain boundaries with resultant grain surfaces inclined at steep angles to the main fracture plane. In the center of Figure 27b is one area of more ductile transgranular fracture distinguished by its fine dimpled appearance.

The contrasting appearance of the fracture surface of an MA07-T6 tear specimen of high fracture toughness (UPE of 1065 in-lb/in^2, tear/Y.S. of 1.43) is shown in the SEM fractographs of Figure 28. Here the fracture path was mostly transgranular with only a minor portion of the fracture surface made up of large facets corresponding to grain boundary shear or cleavage.

Further illustrating the relationship between modes of fracture and fracture toughness is Figure 29, an SEM fractograph of MA08-T6, which had an intermediate fracture toughness (UPE of 480 in-lb/in^2, tear/Y.S. of 1.19) and high strength (76.6 ksi yield strength). Here the mode was about evenly divided between transgranular and intergranular fracture. Also, the grain facets corresponding to the latter mode were generally oriented at only small angles to the main fracture plane, unlike the intergranular shear fracture path of Figure 27.

A replica transmission electron micrograph of the MA05 tear specimen fracture surface corresponding to the SEM of Figure 27 is shown in Figure 30. The major portion of the fracture surface was generated by grain boundary separation with resultant low fracture toughness. On the surfaces of the grains are many fine dimples believed to be initiated by grain boundary precipitate particles averaging 500 Å in major dimension (as previously seen in the transmission micrograph, Figure 23a). Also shown in the lower left region is an area of transgranular fracture in which the elongated shape of the dimples indicates substantial strain occurred here before fracture.

A comparable transmission fractograph for the MA07 specimen of high fracture toughness (Figure 28) is shown in Figure 31. The transgranular fracture surface consists of fine dimples (.2 to 2μ in diameter) each of which appears to have been initiated by an E phase particle corresponding to those that are present in the transmission micrograph of this alloy, Figure 21.

From these studies, it appeared that fracture toughness values of the several alloys included in this investigation were dependent principally on the prevailing mode of fracture, i.e., on the relative areal proportions of the fracture path that were intergranular or transgranular; this relationship has also been found in other Alcoa Research Laboratories investigations of this type. In the lower strength materials, the fracture path was through the grains and appeared to be from the linking up of micro voids generated at dispersoid-matrix interfaces. As the alloy content was increased, the strength of the grains increased to the point that it equalled or exceeded that of the grain boundaries with the result that fracture then took place along the latter to increasing degrees.

The two high strength alloys, MA05 and MA08, had equivalent strengths but significantly different fracture toughness levels corresponding to the relative proportions of intergranular fracture observed in the tear specimens. While metallographic examinations did not positively identify the characteristics of MA08 grain boundaries responsible for the decreased degree of separation along them compared to MA05, it was noted that the grain boundary precipitate in this alloy was the finest and most continuous of those in the materials examined.

Further improvement in fracture toughness at high strength levels thus appears to depend upon maintaining transgranular fracture at such strengths by developing grain boundary characteristics which better resist separation. The effect of

second phase constituent particles (sizes resolved by optical metallography) upon fracture toughness did not appear to be significant at the levels in which they were present in these alloys. Indeed, the difference in toughness of alloys MA05 and MA08 at a yield strength level of 75-76 ksi amply demonstrates that factors other than the relative proportions of second phase particles can have a greater effect on toughness than the second phase particles do. Of these two compositions, MA08 having the larger impurity content and greater volume fraction of second phase particles had distinctly higher fracture toughness. This does not, of course, imply that MA08 of higher purity and lower second phase content than the material tested would not have high toughness.

SUMMARY

The following table summarizes the characteristics of the five alloys relative to the Frankford Arsenal criteria for a cartridge case alloy:

Criterion	MA05 (T6)	MA06 (T6)	MA07 (T6)	MA08 (T6)	MA09 (F)
Y.S. of 80 ksi	78	59	68	76	56
tear/Y.S. of 1.5	.95	1.6	1.4	1.13	1.5
UPE in-lb/in^2	125	1200	1000	450	475
Corrosion and SCR	Good	Good	Good	Good	Excellent

Criterion	MA05 (T6)	MA06 (T6)	MA07 (T6)	MA08 (T6)	MA09 (F)
Temperature Stability	OK	OK	OK	OK	Loss in strength at 165 F
Quench Sensitivity	Low	Very low	Low	Very low	--

Formability performance is not known pending actual trial fabrication of cartridge cases; tensile and hardness data for the annealed-temper stock indicate formability of the heat-treatable alloys should be similar to that of 7075-0.

Solution and precipitation treatments employed in this investigation were conventional practices; solution temperatures were the maximum permissible and quenching was by immersion in room temperature water. Some differences in strength and fracture toughness levels were evident in MA05 and MA08 precipitation hardened by isothermal aging versus that which had been step-aged by relatively short time practices. As Figure 9 shows, the toughness values were highly dependent upon the strength level rather than the type of aging cycle per se; the strength levels were affected by small differences in precipitation temperature as the aging curves indicated the same maximum yield strengths could be obtained by either aging procedure.

While the target strength-toughness criteria were not obtained in any alloy, MA07 and MA08 in particular appear to be improvements in this respect compared to conventional alloys. This is best illustrated in Figures 10 and 11 where

the trend line shown for the Al-Zn-Mg-Cu-Cr alloys is above that for 7075, 7079, and 7178.

The points for MA08, the Al-Zn-Cu-Mg alloy with Mn instead of Cr, were above either of these lines indicating the superior fracture toughness at high strength of this type of alloy. Its superiority appeared to be somewhat greater in resistance to crack propagation than in notch sensitivity (UPE rather than tear/yield strength).

Since a strong relationship was shown between fracture toughness and the mode of fracture in tear testing, studies of the effects of alloy type and content, of thermo-mechanical processing, and of final solution and precipitation treatments upon the ability of grain boundaries to resist separation at high strength levels appear to offer the most likely area for improvement in fracture toughness in further research.

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TABLE 1

CHEMICAL COMPOSITION OF EXPERIMENTAL CARTRIDGE CASE ALLOYS

Alloy		Zn	Mg	Cu	Mn	Cr	Si	Fe	Ti	Be
MA05	Ingot	6.72	2.78	1.26	.00	.17	.02	.02	.02	.000
S-362033	Sheet*	6.39	2.63	1.21	.00	.17	.01	.03	.02	.000
MA06	Ingot	4.29	2.15	1.35	.00	.15	.01	.02	.02	.000
S-362034	Sheet*	4.03	2.03	1.34	.00	.15	.01	.03	.02	.000
MA07	Ingot	5.11	2.51	1.16	.00	.13	.02	.03	.02	.000
S-362035	Sheet*	4.84	2.41	1.15	.00	.13	.02	.04	.02	.000
MA08	Ingot	5.86	2.25	2.37	.29	.00	.02	.06	.04	.000
S-362036	Sheet*	5.84	2.27	2.51	.30	.00	.02	.07	.05	.000
MA09	Ingot A	.02	7.65	.02	.08	.09	.02	.02	.05	.004
S-362037	Ingot C	.02	7.63	.01	.08	.09	.02	.02	.03	.004
	Sheet*	.03	7.76	.01	.08	.09	.02	.03	.04	.006

* Spectrographic analysis of remelted sheet sample.

Analytical Chemistry Reports 68-092406, 68-102913, 69-032410.

TABLE 2

FABRICATING PROCEDURE FOR .150" AND .187" FLAT STRIP SHEET IN FIVE EXPERIMENTAL CARTRIDGE CASE ALLOYS

	MA05	MA06	MA07	MA08	MA09
Ingot Size	12" x 38"	12" x 38"	12" x 38"	12" x 38"	8" x 38"
Scalp	1/2" per side	1/2" per side	1/2" per side	1/2" per side	1/2" per side
Hot Roll	.750"	.750"	.750"	.750"	.750"
Continuous Mill Roll	1/2 to .225" 1/2 to .200"	1/2 to .225" 1/2 to .200"	1/2 to .225" 1/2 to .200"	1/2 to .225" 1/2 to .200"	1 to .225" 1 to .200"
Cold Roll	.225"-.187" or .200"-.150"	.225"-.187" or .200"-.150"	.225"-.187" or .200"-.150"	.225"-.187" or .200"-.150"	.225"-.187" or .200"-.150"
Anneal	2 hours at 850 F; furnace cool to 450 F; hold 4 hours at 450 F				1 hr. at 700 F

TABLE 3

TENSILE AND ELECTRICAL CONDUCTIVITY DATA FOR ELEVATED TEMPERATURE AGING OF .063" MA05 SHEET

Sample	Aging Practice	Tensile Strength ksi	Yield Strength ksi	Elong. % in 2"	El. Conductivity % IACS
S-362033-1	1 hr./250 F	79.6	62.0	19.0	30.3
-2	3 hr./250 F	83.0	69.3	17.0	30.7
-3	6 hr./250 F	84.8	73.0	15.8	31.1
-4	10 hr./250 F	85.7	74.3	15.0	31.3
-5	16 hr./250 F	85.8	76.4	14.0	31.5
-6	24 hr./250 F	86.0	77.4	13.2	31.8
-7	36 hr./250 F	86.1	78.4	12.8	32.1
-8	1 hr./275 F	82.5	70.0	16.2	31.2
-9	3 hr./275 F	84.0	74.0	15.0	31.7
-10	6 hr./275 F	84.9	76.2	13.2	32.1
-11	10 hr./275 F	85.0	77.8	13.0	32.3
-12	16 hr./275 F	85.2	78.8	12.8	32.9
-13	24 hr./275 F	85.0	79.1	12.0	33.4
-14	36 hr./275 F	84.2	78.6	11.5	33.9
-15	3/250 + 1/310	83.3	72.8	14.8	31.8
-16	3/250 + 3/310	83.5	75.8	13.5	32.5
-17	3/250 + 5/310	83.8	77.7	12.8	33.0
-18	3/250 + 8/310	84.1	78.3	12.0	33.4
-1B	3/250 + 12/310	83.1	77.3	11.5	35.1
-2B	3/250 + 16/310	82.8	76.6	11.5	35.5
-19	3/250 + 1/325	83.1	73.7	14.0	32.2
-20	3/250 + 3/325	83.0	76.8	12.2	33.2
-21	3/250 + 5/325	83.7	78.1	11.8	33.7
-22	3/250 + 8/325	83.8	77.4	11.0	34.6
-23	3/250 + 1/340	82.7	76.6	12.5	33.6
-24	3/250 + 3/340	81.8	75.3	10.8	36.4
-25	3/250 + 5/340	80.8	74.3	11.0	37.9
-26	3/250 + 8/340	78.5	71.6	11.0	39.0

1. All tests transverse to rolling direction; averages of two tests listed.

2. Solution heat treatment 1 hour at 880-890 F, cold water quench; elevated temperature aging followed minimum of 4 days room temperature aging. Heating rate to 250 or 275 F at 90 F/hour.

3. M.T. Reports 040369B 5/22/69 and 8/25/69.

TABLE 4

TENSILE AND ELECTRICAL CONDUCTIVITY DATA FOR ELEVATED TEMPERATURE AGING OF .063" MA06 SHEET

Sample	Aging Practice	Tensile Strength ksi	Yield Strength ksi	Elong. % in 2"	El. Conductivity % IACS
S-362034-1	1 hr./250 F	63.5	43.5	21.0	32.9
-2	3 hr./250 F	64.3	47.9	18.0	33.4
-3	6 hr./250 F	66.1	51.0	16.5	33.9
-4	10 hr./250 F	66.9	53.1	16.0	34.0
-5	16 hr./250 F	67.4	55.3	15.0	34.5
-6	24 hr./250 F	67.9	57.3	14.2	34.5
-7	36 hr./250 F	69.1	57.9	15.2	35.0
-8	1 hr./275 F	64.0	48.0	18.8	33.8
-9	3 hr./275 F	65.3	52.8	16.5	34.4
-10	6 hr./275 F	66.7	55.8	15.0	34.6
-11	10 hr./275 F	67.3	56.4	14.8	35.0
-12	16 hr./275 F	67.7	56.8	14.2	35.5
-13	24 hr./275 F	67.8	57.6	14.0	36.2
-14	36 hr./275 F	68.5	57.8	13.8	36.0
-15	3/250 + 1/310	64.9	51.4	16.0	34.3
-16	3/250 + 3/310	66.3	54.8	15.0	35.0
-17	3/250 + 5/310	67.0	55.9	14.5	35.4
-18	3/250 + 8/310	67.4	56.5	14.2	35.3
-3B	3/250 + 12/310	68.7	58.5	12.5	36.6
-4B	3/250 + 16/310	69.0	59.1	12.5	36.8
-19	3/250 + 1/325	65.1	52.5	16.2	34.7
-20	3/250 + 3/325	66.6	55.6	14.5	35.6
-21	3/250 + 5/325	67.0	56.0	13.5	36.1
-22	3/250 + 8/325	68.1	57.1	13.0	36.6
-7B	3/250 + 12/325	68.7	58.8	11.8	38.4
-8B	3/250 + 16/325	68.8	58.8	12.0	38.4
-23	3/250 + 1/340	66.1	54.8	14.0	36.0
-24	3/250 + 3/340	67.5	56.9	12.5	38.0
-25	3/250 + 5/340	67.9	57.8	11.8	39.4
-26	3/250 + 8/340	67.0	56.9	11.5	40.7

1. All tests transverse to rolling direction; averages of two tests listed.

2. Solution heat treatment 1 hour at 950-960 F; cold water quench; elevated temperature aging followed minimum of 4 days room temperature aging. Heating rate to 250 or 275 F at 90 F/hour.

3. M. T. Report 040369B.

TABLE 5

TENSILE AND ELECTRICAL CONDUCTIVITY DATA FOR ELEVATED TEMPERATURE AGING OF .063" MA07 SHEET

Sample	Aging Practice	Tensile Strength ksi	Yield Strength ksi	Elong. % in 2"	El. Conductivity % IACS
S-362035-1	1 hr./250 F	68.4	49.2	22.8	31.5
-2	3 hr./250 F	70.5	55.0	18.2	31.9
-3	6 hr./250 F	73.0	60.2	16.8	32.5
-4	10 hr./250 F	73.7	62.6	15.0	32.8
-5	16 hr./250 F	74.8	65.0	15.0	32.9
-6	24 hr./250 F	75.8	67.1	14.5	33.0
-7	36 hr./250 F	75.7	67.9	14.0	33.3
-8	1 hr./275 F	70.6	56.8	17.0	32.4
-9	3 hr./275 F	72.4	61.0	15.8	32.7
-10	6 hr./275 F	73.7	64.3	15.0	33.0
-11	10 hr./275 F	75.2	66.7	13.8	33.2
-12	16 hr./275 F	75.7	68.2	13.8	33.5
-13	24 hr./275 F	76.1	68.7	13.5	33.7
-14	36 hr./275 F	75.8	68.5	13.0	34.2
-15	3/250 + 1/310	72.1	62.3	14.5	32.7
-16	3/250 + 3/310	74.0	65.7	13.2	33.4
-17	3/250 + 5/310	74.5	66.8	13.8	33.7
-18	3/250 + 8/310	75.0	67.6	13.8	33.9
-5B	3/250 + 12/310	75.6	67.8	13.0	34.7
-6B	3/250 + 16/310	75.7	67.9	12.8	35.1
-19	3/250 + 1/325	72.9	63.1	15.0	32.6
-20	3/250 + 3/325	74.6	66.8	13.5	33.9
-21	3/250 + 5/325	74.8	67.3	13.0	34.4
-22	3/250 + 8/325	75.0	67.6	12.0	34.9
-9B	3/250 + 12/325	75.0	67.0	11.0	36.8
-10B	3/250 + 16/325	75.4	67.2	11.5	36.5
-23	3/250 + 1/340	73.2	65.0	13.2	34.4
-24	3/250 + 3/340	74.4	67.1	11.0	36.1
-25	3/250 + 5/340	75.5	68.4	11.0	37.4
-26	3/250 + 8/340	74.3	67.0	11.0	38.5

1. All tests transverse to rolling direction; averages of two tests listed.

2. Solution heat treatment 1 hour at 950-960 F; cold water quench; elevated temperature aging followed minimum of 4 days room temperature aging. Heating rate to 250 or 275 F at 90 F/hour.

3. M. T. Report 040369B.

TABLE 6

TENSILE AND ELECTRICAL CONDUCTIVITY DATA FOR ELEVATED TEMPERATURE AGING OF .063" MA08 SHEET

Sample	Aging Practice	Tensile Strength ksi	Yield Strength ksi	Elong. % in 2"	El. Conductivity % IACS
S-362036-1	1 hr./250 F	79.4	60.8	19.5	26.6
-2	3 hr./250 F	81.0	64.6	17.8	27.1
-3	6 hr./250 F	82.0	67.4	16.5	27.5
-4	10 hr./250 F	82.5	68.7	16.0	27.8
-5	16 hr./250 F	82.7	69.5	15.2	27.8
-6	24 hr./250 F	83.3	70.6	14.8	28.2
-7	36 hr./250 F	83.6	72.1	14.2	28.4
-8	1 hr./275 F	80.9	66.3	16.0	27.3
-9	3 hr./275 F	82.2	69.1	15.0	28.3
-10	6 hr./275 F	83.1	71.1	14.0	28.8
-11	10 hr./275 F	83.4	73.1	13.5	29.1
-12	16 hr./275 F	84.1	75.0	12.8	29.6
-13	24 hr./275 F	84.6	76.5	12.2	30.2
-14	36 hr./275 F	85.2	78.2	12.0	31.0
-11B	10 hr./300 F	85.1	77.2	11.2	30.2
-12B	16 hr./300 F	85.7	78.6	11.2	31.1
-13B	24 hr./300 F	85.8	79.4	11.2	31.9
-14B	36 hr./300 F	85.1	78.4	10.5	32.7
-15	3/250 + 1/310	81.4	67.5	15.0	28.3
-16	3/250 + 3/310	83.0	71.9	14.0	29.2
-17	3/250 + 5/310	83.9	74.5	13.0	29.7
-18	3/250 + 8/310	84.3	76.2	11.2	30.1
-27	3/250 + 12/310	84.6	78.4	11.0	30.8
-28	3/250 + 18/310	85.2	79.6	11.0	31.8
-29	3/250 + 24/310	85.0	79.6	10.3	32.3
-19	3/250 + 1/325	81.9	69.7	14.0	28.6
-20	3/250 + 3/325	83.9	75.5	11.8	30.2
-21	3/250 + 5/325	84.5	77.6	11.5	30.8
-22	3/250 + 8/325	85.4	79.9	10.5	31.9
-30	3/250 + 12/325	85.0	80.1	10.5	32.9
-31	3/250 + 18/325	83.9	78.7	10.5	34.0
-23	3/250 + 1/340	84.5	77.5	11.5	30.7
-24	3/250 + 3/340	84.6	80.2	10.2	33.5
-25	3/250 + 5/340	83.3	77.8	10.0	34.9
-26	3/250 + 8/340	79.4	72.3	10.0	36.1
-15B	3/275 + 8/325	85.1	79.3	10.5	32.9
-16B	3/275 + 12/325	83.4	77.3	9.8	34.5

1. All tests transverse to rolling direction; average of two tests listed.
2. Solution heat treatment 1 hour at 900-910 F, cold water quench; elevated temperature aging followed minimum of 4 days room temperature aging. Heating rate to 250, 275 or 300 F at 90 F/hour.
3. M.T. Report 040369B.

TABLE 9

TENSILE AND TEAR TEST RESULTS FOR .063" SHEET IN MA05, MA06, MA07, MA08 AND MA09 ALLOYS

				Longitudinal						Transverse					
Alloy - Temper Type	Sample	Aging Practice hours/°F	Electrical Conductivity % IACS	Tensile Strength ksi	Yield Strength ksi	Elongation % in 2"	Tear Strength ksi	Tear Strength / Yield Strength	Unit Propagation Energy in-lb/in²	Tensile Strength ksi	Yield Strength ksi	Elongation % in 2"	Tear Strength	Tear Strength / Yield Strength	Unit Propagation Energy in-lb/in²
MA05-T6	362033-9	3/250 + 5/325	34.7	84.1	77.6	11.0	78.9	1.01	125	83.4	76.8	11.0	77.7	1.01	140
"	373264-7	"	34.4	83.7	76.8	12.0	78.5	1.02	135	83.3	76.1	11.5	74.9	.98	125
	Average			83.9	77.2	11.5	78.7	1.01	130	83.3	76.4	11.2	76.3	.99	132
"	362033-6	24/275	32.6	86.0	79.0	12.0	78.5	.99	180	85.2	78.1	12.2	74.3	.95	150
"	373264-2	"	32.5	85.5	78.0	12.0	76.1	.98	145	84.5	77.4	12.0	71.1	.92	105
"	362033-10	"	32.6	86.6	78.5	13.0	73.8	.94	125	85.3	77.8	13.0	75.3	.97	125
"	373264-8	"	32.9	85.7	78.3	13.0	72.1	.92	60	84.8	78.1	12.0	74.4	.95	115
	Average			85.9	78.4	12.5	75.1	.96	127	85.0	77.8	12.3	73.8	.95	124
MA06-T6	362034-3	3/250 + 5/340	39.2	69.2	59.8	12.0	93.4	1.56	1035	68.9	59.4	11.5	93.4	1.57	1160
"	362034-6	24/275	35.2	69.8	59.6	14.8	95.8	1.61	1215	69.2	59.3	14.8	97.3	1.64	1320
MA07-T6	362035-3	3/250 + 5/340	36.5	75.4	67.9	12.0	99.1	1.46	965	74.9	67.8	11.5	97.0	1.43	1085
"	373266-1	"	37.5	75.6	67.8	11.8	95.6	1.41	890	74.5	66.9	11.8	97.0	1.45	1000
	Average			75.5	67.8	11.9	97.3	1.43	927	74.7	67.3	11.6	97.0	1.44	1042
"	362035-6	24/275	33.7	76.9	69.0	13.2	99.2	1.44	970	76.2	68.5	13.2	98.0	1.43	1065
"	373266-2	"	33.4	77.1	68.2	14.0	96.2	1.41	855	75.7	67.0	13.5	96.2	1.43	1045
	Average			77.0	68.6	13.6	97.7	1.42	912	75.9	67.7	13.3	97.1	1.43	1055
MA08-T6	362036-9	3/250 + 9/325	33.3	85.4	80.1	10.3	79.1	.99	265	84.8	78.2	10.0	80.7	1.03	290
"	373267-7	"	33.3	85.5	78.9	10.0	77.6	.99	265	84.1	78.3	10.5	78.0	.99	225
	Average			85.4	79.5	10.1	78.3	.99	265	84.4	78.2	10.2	79.3	1.01	257
"	362036-6	36/275	29.9	84.9	75.8	12.0	88.1	1.16	585	84.7	76.6	12.0	91.2	1.19	480
"	373267-2	"	29.9	85.0	74.9	12.5	87.9	1.18	550	84.6	75.9	12.0	87.0	1.15	445
"	362036-10	"	30.4	85.7	77.0	11.0	87.5	1.13	455	85.6	77.0	12.0	85.1	1.10	475
"	373267-8	"	30.3	84.6	76.5	11.5	81.5	1.06	475	85.0	76.9	11.3	85.1	1.11	350
	Average			85.0	76.0	11.7	86.2	1.13	516	85.0	76.6	11.8	87.1	1.14	438
MA09-F	362037-3	---	--	71.6	60.7	9.5	86.9	1.43	495	71.7	56.1	12.0	87.3	1.56	475
"	373268-1	---	--	72.7	61.5	9.0	85.5	1.39	475	71.2	56.1	12.0	86.5	1.54	--
	Average			72.1	61.1	9.2	86.2	1.41	485	71.4	56.1	12.0	86.9	1.55	475

1. S362033-37 rolled from .187" nominal stock; S373264-8 rolled from .150" nominal stock.
2. Four days minimum room temperature aging interval before elevated temperature aging. Heating rate to initial aging temperature 90F/hour.
3. Solution heat treatment of 1 hour at 890F for MA05; 1 hour at 960F for MA06, MA07; 1 hour at 910F for MA08
4. MT Reports 040369 B 6/20/69, 7/3/69, 7/14/69, 8/6/69.
5. Tensile test results are averages of two tests; tear test results average of three tests except where diagonal fractures were deleted.

Table 10

RESISTANCE TO STRESS CORROSION CRACKING OF LABORATORY FABRICATED 0.064" THICK SHEET OF EXPERIMENTAL CARTRIDGE CASE ALLOYS

		Original Properties(1)			Unstressed		Stressed				Stressed Preforms		
S. No.	Alloy & Temper	T.S. ksi	Y.S. ksi	% El.	Length of Exposure	% Loss (2) in T.S.	Applied Stress, % Y.S.	F/N (3)	Days	% Loss (1) in T.S. (12 wks.)	Test Direction	F/N (3)	Days
326033	MA05-T6	80.7	74.3	10.8	4 wks.	8	75	0/3	OK-84	31	W	0/3	OK-84
					12 wks.	15	50	0/3	OK-84	27	X	0/2	OK-84
326034	MA06-T6	68.9	59.7	12.7	4 wks.	5	75	0/3	OK-84	20	W	0/3	OK-84
					12 wks.	13	50	0/3	OK-84	18	X	0/2	OK-84
326035	MA07-T6	74.8	67.5	12.7	4 wks.	8	75	0/3	OK-84	19	W	0/3	OK-84
					12 wks.	13	50	0/3	OK-84	21	X	0/2	OK-84
326036	MA08-T6	82.5	76.6	10.0	4 wks.	8	75	0/3	OK-84	23	W	0/3	OK-84
					12 wks.	18	50	0/3	OK-84	20	X	0/2	OK-84
326037	MA09-F	72.7	56.6	12.2	4 wks.	1	75	0/3	OK-84	2	W	0/3	OK-84
					12 wks.	2	50	0/3	OK-84	2	X	0/2	OK-84
342703	7075-T6 (ARL Stock)	82.7	74.7	10.5	4 wks.	7	75	0/3	OK-84	15	W	0/3	OK-84
					12 wks.	11	50	0/3	OK-84	15	X	0/2	OK-84

Notes:

(1) Results are the average of tests of triplicate transverse tensile specimens.

(2) Results are the average of tests of duplicate transverse tensile specimens.

(3) F/N denotes number of specimens failed over exposed.

(4) Solution heat treatment 1 hr. at 890F for MA05; 1 hr. at 960F for MA06, MA07; 1 hr. at 910F for MA08. Elevated temperature aging after 4 days at room temperature: 3 hrs. at 250F plus 5 hrs. at 340F for MA05, MA06, MA07; 3 hrs. at 250F plus 9 hrs. at 340F for MA08.

TABLE 11

TENSILE AND TEAR TEST RESULTS FOR MA05, MA06, MA07, MA08 AND MA09
AFTER EXTENDED PERIODS AT -110F AND AT 165F

			Longitudinal						Transverse					
Alloy and Temper Type	Sample	Post Aging Treatment	Tensile Strength ksi	Yield Strength ksi	Elongation % in 2"	Tear Strength ksi	Tear/YS	UPE in-lb/in²	Tensile Strength ksi	Yield Strength ksi	Elongation % in 2"	Tear Strength ksi	Tear/YS	PE in-lb/in²
MA05-T6	362033	H.T. and aged only	81.2	74.7	10.8	81.8	1.10	265	80.8	74.7	11.0	88.9	1.19	330
		After 30 days at -110F	81.1	74.6	9.3	89.7	1.20	245	80.5	74.3	12.0	90.7	1.22	255
		After 30 days at 165F	82.7	77.1	11.0	74.1	.96	180	81.6	75.5	11.0	81.6	1.08	295
MA06-T6	362034	H.T. and aged only	69.2	59.8	12.0	93.4	1.56	1035	68.9	59.4	11.5	93.4	1.57	1165
		After 30 days at -110F	69.2	59.7	11.5	92.4	1.55	995	69.1	59.8	12.0	92.3	1.54	1115
		After 30 days at 165F	69.1	59.4	11.5	93.4	1.57	980	70.5	62.4	12.0	94.3	1.51	1065
MA07-T6	362035	H.T. and aged only	75.4	67.9	12.0	99.1	1.46	965	74.9	67.8	11.5	97.0	1.43	1065
		After 30 days at -110F	75.4	67.4	12.0	97.1	1.44	925	74.6	67.5	12.0	95.0	1.41	975
		After 30 days at 165F	77.0	70.4	12.0	97.7	1.39	645	76.3	69.9	12.0	94.6	1.35	695
MA08-T6	362036	H.T. and aged only	81.9	75.2	10.0	84.6	1.12	455	81.8	75.6	10.3	81.1	1.07	380
		After 30 days at -110F	82.3	76.3	11.0	77.8	1.02	260	81.5	75.5	10.0	77.2	1.02	265
		After 30 days at 165F	83.4	77.8	11.0	79.6	1.02	325	83.1	77.5	11.0	76.6	.99	250
MA09-F	362037	H.T. and aged only	71.6	60.7	9.5	86.9	1.43	495	71.7	56.1	12.0	87.3	1.55	475
		After 30 days at -110F	71.8	60.2	8.0	86.3	1.43	515	71.4	56.4	13.0	87.2	1.54	535
		After 30 days at 165F	65.6	48.6	13.0	86.8	1.78	1125	64.7	47.0	16.5	86.5	1.84	1060

1. Solution heat treatment 1 hour at 890F for MA05; 1 hour at 960F for MA06, MA07; 1 hour at 910F for MA08.

2. Elevated temperature aging after 4 days at room temperature: 3 hours at 250F plus 5 hours at 340F for MA05, MA06, MA07; 3 hours at 250F plus 9 hours at [illegible] for MA08; heating rate to initial aging temperature 90F/hour.

3. Tensile data average of two tests; tear test data average of three tests except diagonal fractures deleted.

4. MT Reports 040369 B 6/20/69, 7/3/69, 8/5/69, 9/12/69.

TABLE 12

TENSILE TEST AND HARDNESS DATA FOR
ANNEALED TEMPER STOCK FOR CARTRIDGE CASE DEVELOPMENT

Alloy and Temper	Sample	Nominal Thickness In.	Longitudinal Tensile Strength ksi	Longitudinal Yield Strength ksi	Longitudinal Elongation % in 2"	Transverse Tensile Strength ksi	Transverse Yield Strength ksi	Transverse Elongation % in 2"	R_{15T}	$\bar{r}$	$\bar{n}$
MA05-0	362033	.187	29.4	11.0	19.5	29.7	11.2	18.5	67	.53	.195
	373264	.150	28.7	11.6	19.8	29.3	11.7	20.0	66		
MA06-0	362034	.187	28.0	9.3	22.8	28.3	9.3	22.8	63	.53	.21[illegible]
	373265	.150	28.2	9.4	22.2	--	--	--	60		
MA07-0	362035	.187	29.1	10.0	22.0	29.4	10.1	21.8	62	.53	.212
	373266	.150	28.4	10.6	21.8	28.7	10.0	21.5	65		
MA08-0*	362036	.187	32.3	11.6	19.0	31.8	11.6	20.2	66	.54	.206
	373267	.150	32.8	12.8	18.2	31.9	13.2	18.2	66.5		
MA09-0	362037	.187	51.5	23.3	28.8	50.8	23.3	31.5	79	.58	.332
	373268	.150	51.9	23.8	29.8	50.7	23.6	29.5	79		

1. Tensile test data average of two tests.

2. MT Reports 040369B 9/9/69

* Tests made approximately one and six months after annealing indicate some age hardening had occurred. Listed data are averages of the two tests.

TABLE 13

TENSILE PROPERTIES OF MA05, MA06, MA07 AND MA08 OF VARIOUS THICKNESSES QUENCHED INTO COLD OR BOILING WATER

			Cold Water Quench			Boiling Water Quench		
Alloy	S. No.	Nominal Thickness inch	Tensile Strength ksi	Yield Strength ksi	% Elong. in 2"	Tensile Strength ksi	Yield Strength ksi	% Elong. in 2"
MA05	362033	.063	82.7	78.2	11.5	78.8	71.4	12.0
		.125	83.9	77.8	11.0	78.1	70.0	12.0
		.187	84.0	78.0	13.0	75.5	64.9	13.0
		.250	84.5	78.6	12.0	74.7	63.6	12.0
		.500	84.2	77.5	14.0	68.2	54.6	15.0
MA06	362034	.063	68.0	58.6	12.0	68.0	59.0	12.0
		.125	70.3	61.1	13.0	69.5	55.8	13.0
		.187	69.3	60.1	15.0	68.3	58.0	15.0
		.250	70.4	50.6	16.0	69.3	58.9	14.5
		.500	70.3	60.6	15.5	68.6	57.7	13.5
MA07	362035	.063	74.6	67.7	12.0	73.1	65.8	12.0
		.125	75.3	67.5	13.0	74.1	65.7	12.5
		.187	75.0	67.3	15.0	73.0	65.0	13.0
		.250	74.9	67.1	15.0	72.5	63.6	13.0
		.500	74.9	67.6	18.5	70.7	61.7	16.5
MA08	362036	.063	84.3	79.6	10.5	82.7	76.1	9.0
		.125	85.9	80.7	11.5	82.8	76.0	6.5
		.187	86.1	80.2	12.0	82.9	76.0	8.0
		.250	85.7	79.4	12.0	81.9	75.5	6.5
		.500	85.5	79.4	12.0	80.9	74.9	6.0

1. Test direction transverse to rolling direction.
2. Results are averages of two tests.
3. MA05 solution heat treat 90 minutes at 890 F; MA06 and MA07, 90 minutes at 960 F; MA08 90 minutes at 910 F.
4. All samples room temperature aged four days minimum; then MA05 3 hours at 250 + 5 hours at 325 F; MA06 and MA07 3 hours at 250 + 5 hours at 340 F; MA08 3 hours at 250 + 9 hours at 325 F. Heating rate to initial aging temperature 90 F/hour.
5. M.T. 040369B, 8/20/69.

Table 14

EFFECT OF LOW TEMPERATURE THERMAL TREATMENTS ON TENSILE PROPERTIES AND DEGREE OF RECRYSTALLIZATION OF MA09-F SHEET

Thermal Treatment					
Time hrs.	Temp. °F	Degree of Recrystallization	Tensile Strength ksi	Yield Strength ksi	Elongation % in 2"
--	--	--	71.7	56.1	12.0
1	425	None	61.9	40.2	19.3
4	425	None	62.2	38.2	20.0
8	425	None	62.0	37.0	15.3
12	425	None	61.5	36.1	15.5
1	450	None	60.1	38.6	19.3
4	450	None	60.2	36.1	17.5
8	450	None	59.2	34.7	16.5
12	450	None	58.0	33.2	17.0
1	500	None	58.5	36.5	21.0
4	500	None	57.3	33.9	18.5
8	500	None	56.5	33.1	19.5
12	500	None	56.2	32.7	19.8
1	550	Partial	56.2	32.8	21.8
4	550	Partial	55.4	31.3	21.0
8	550	Partial	54.9	30.7	21.0
12	550	Partial	54.7	30.5	21.5

Notes: (1) Data for .063" sheet from S-362037.

(2) Degree of recrystallization from X-ray diffraction analysis.
X-ray Report 9248, dated September 19, 1969.
M.T. Report 040369-B, dated October 15, 1969.

(3) Tensile test results average of two tests in transverse direction.

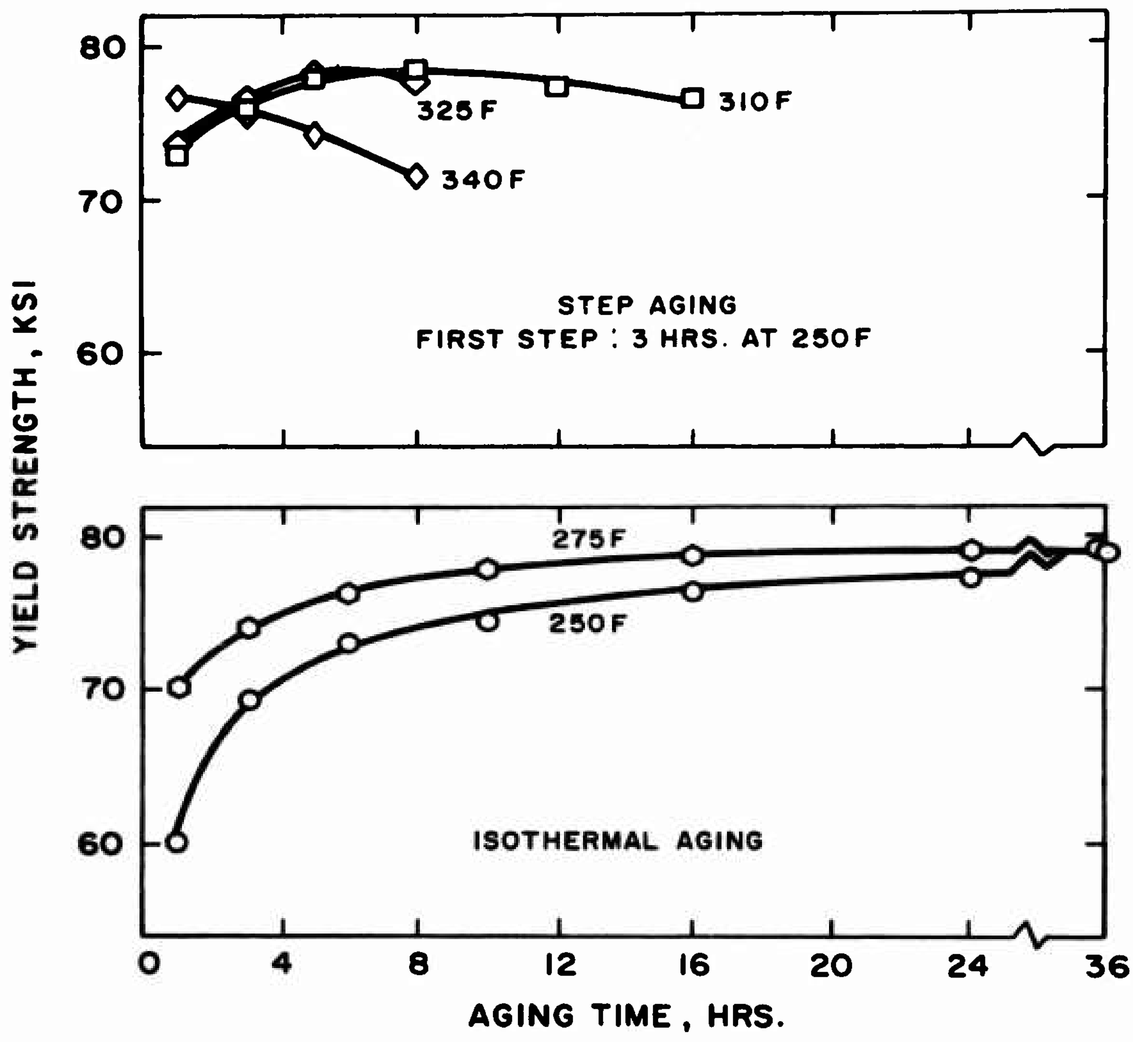


FIG. 1

Precipitation Treatment Curves - Transverse Yield Strength vs Aging Time for .063 inch MA05-T6 Sheet.

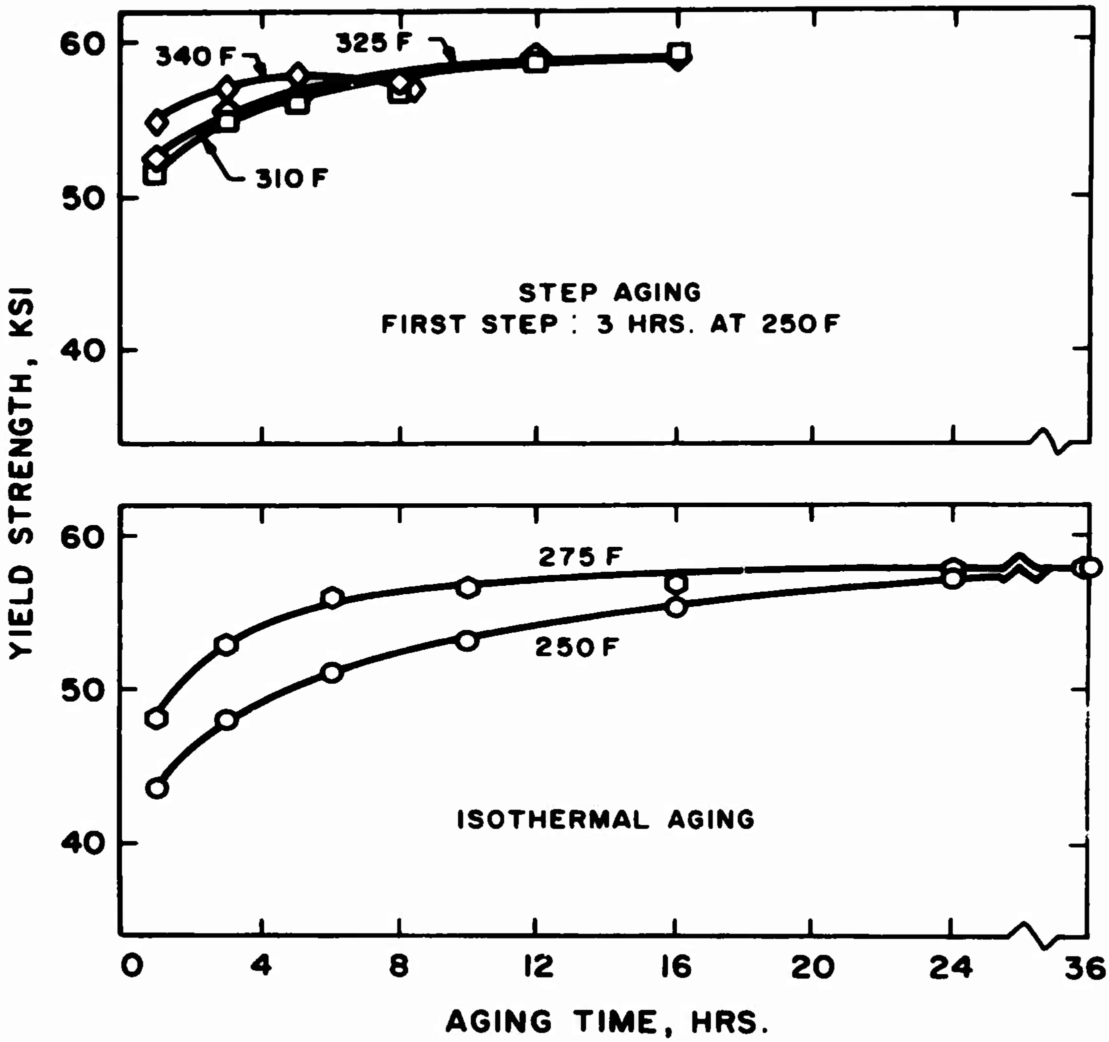


FIG. 2

Precipitation Treatment Curves - Transverse Yield Strength vs Aging Time for .063 inch MA06-T6 Sheet.

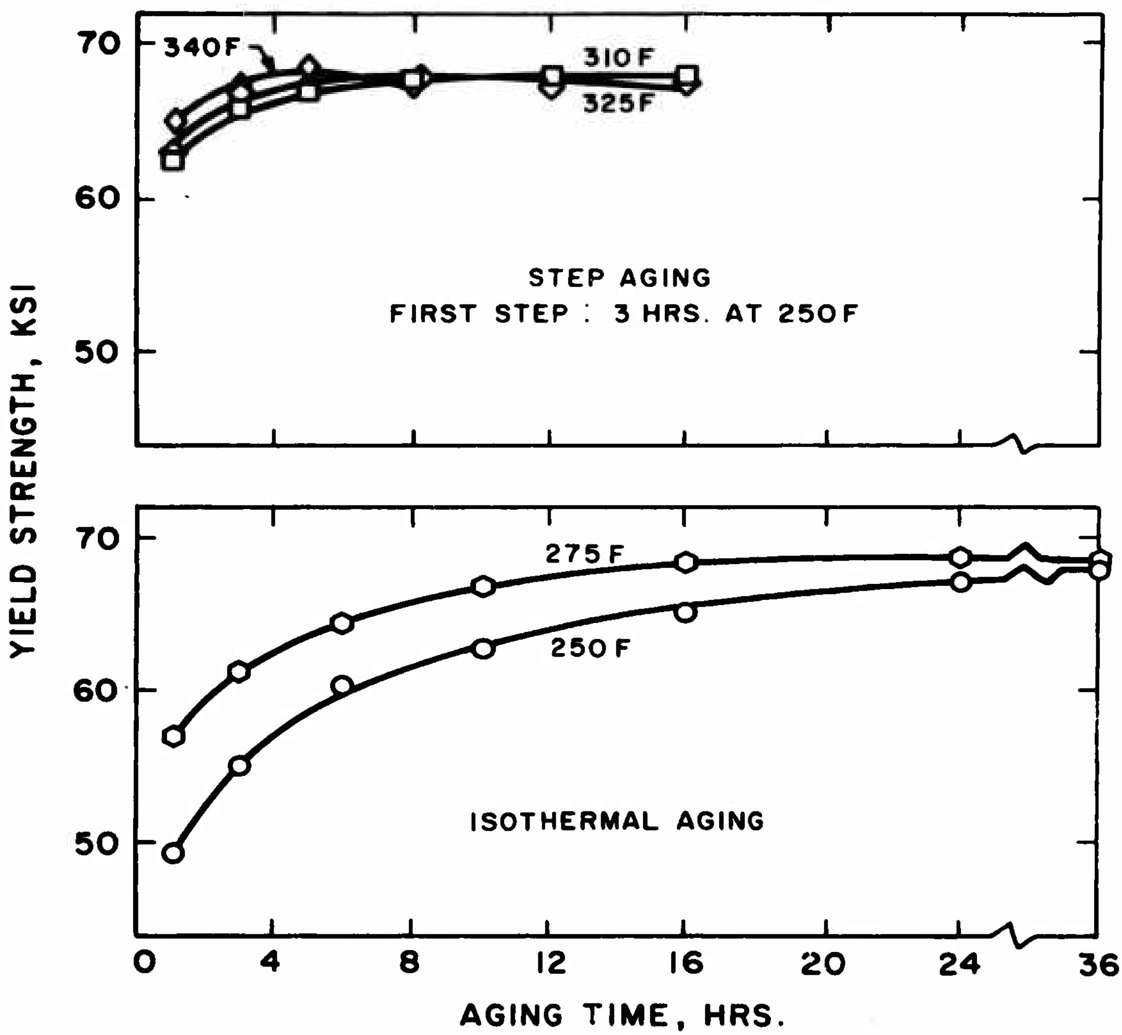


FIG. 3

Precipitation Treatment Curves - Transverse Yield Strength vs Aging Time for .063 inch MA07-T6 Sheet.

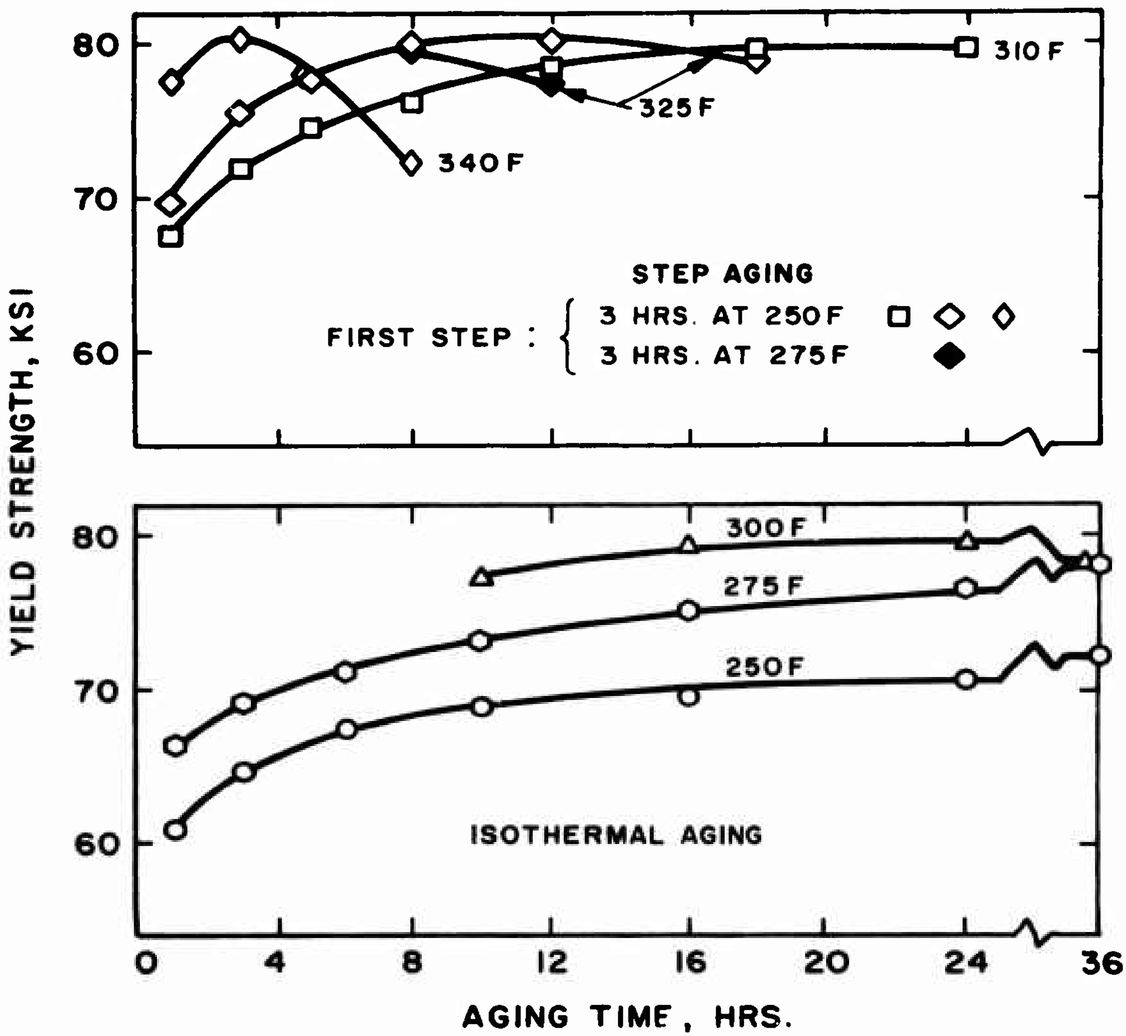


FIG. 4

Precipitation Treatment Curves - Transverse Yield Strength vs Aging Time for .063 inch MA08-T6 Sheet.

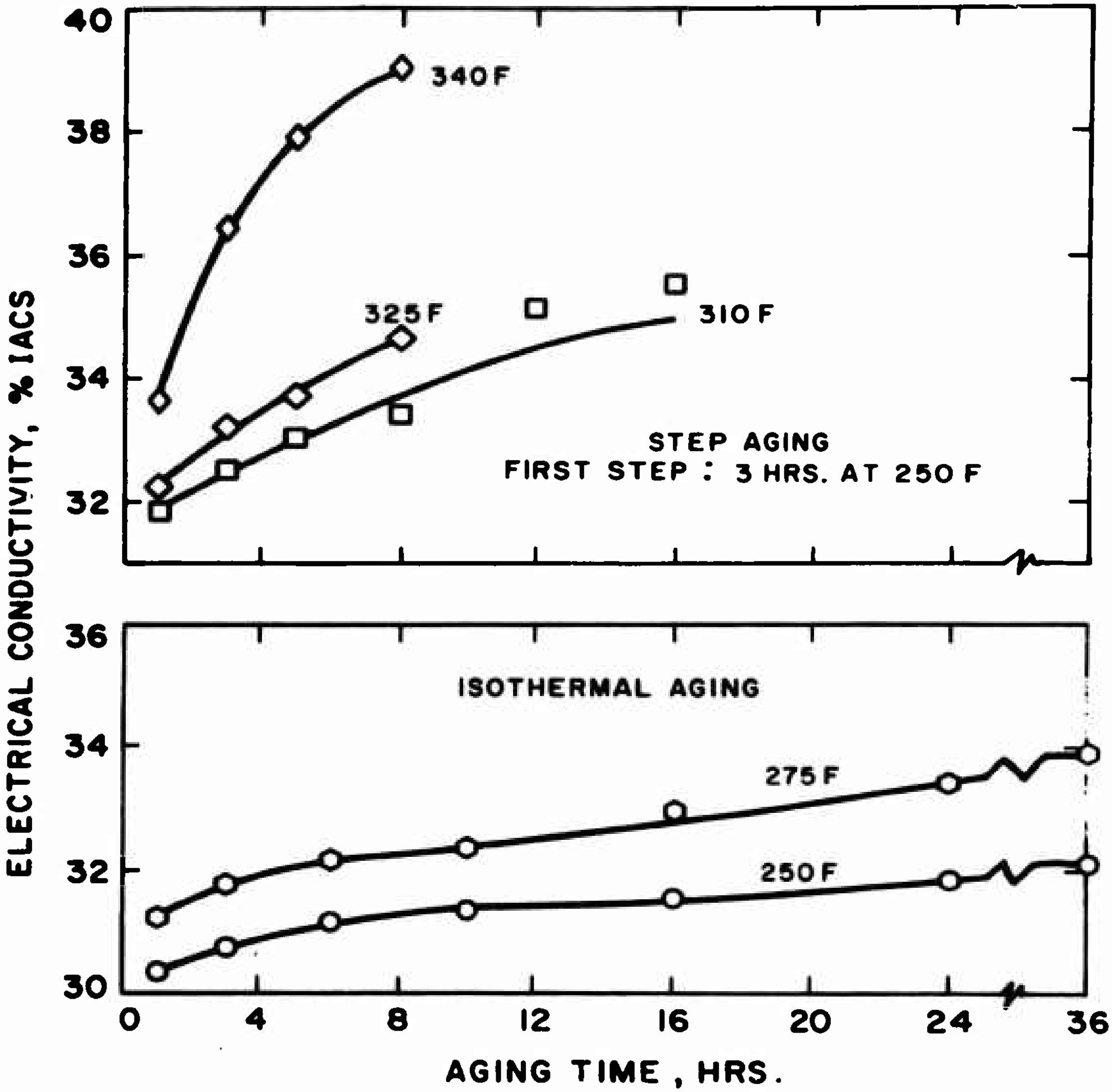


FIG. 5

Precipitation Treatment Curves - Electrical Conductivity vs Aging Time for .063 inch MA05-T6 Sheet.

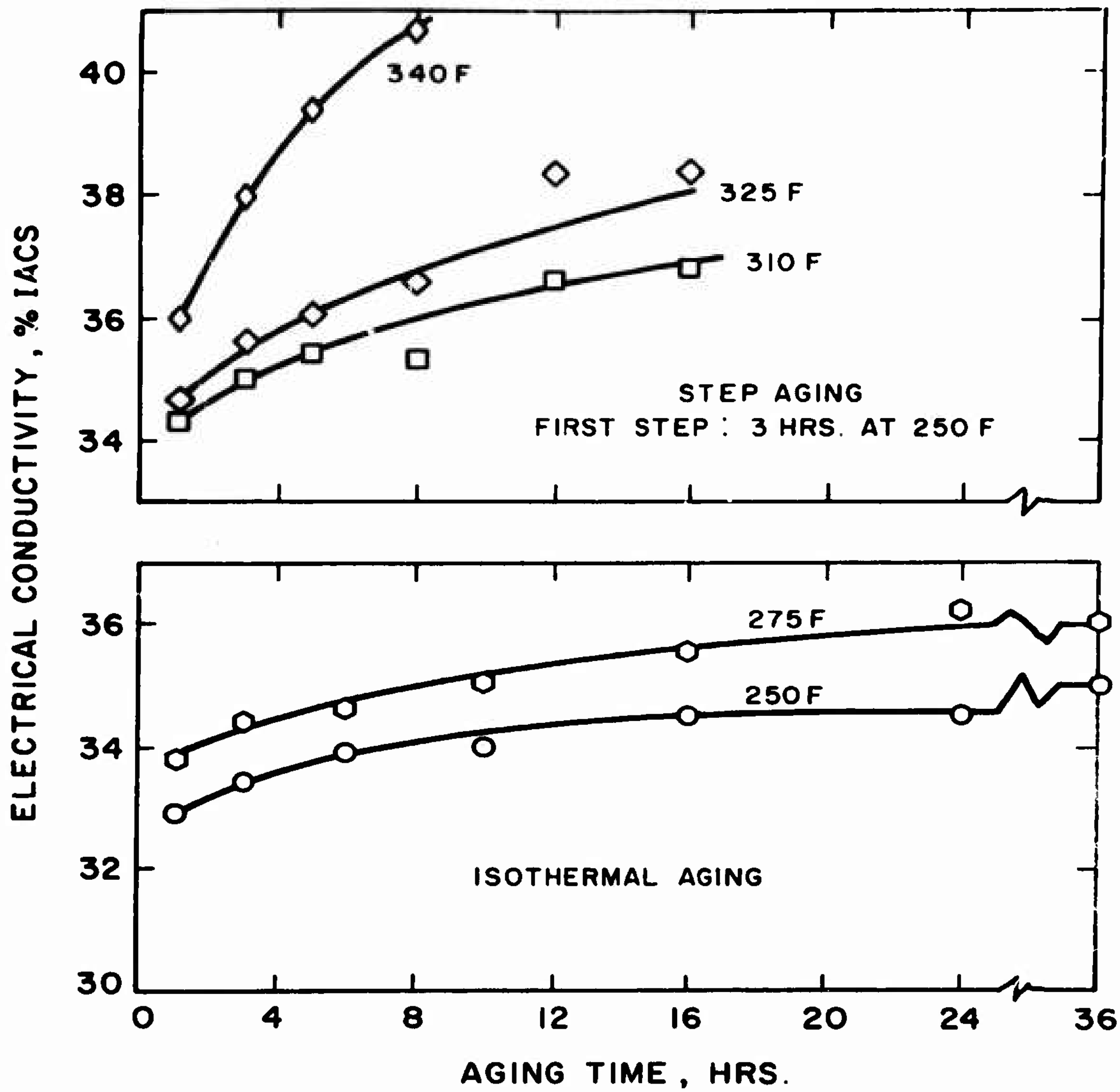


FIG. 6

Precipitation Treatment Curves - Electrical Conductivity vs Aging Time for .063 inch MA06-T6 Sheet.

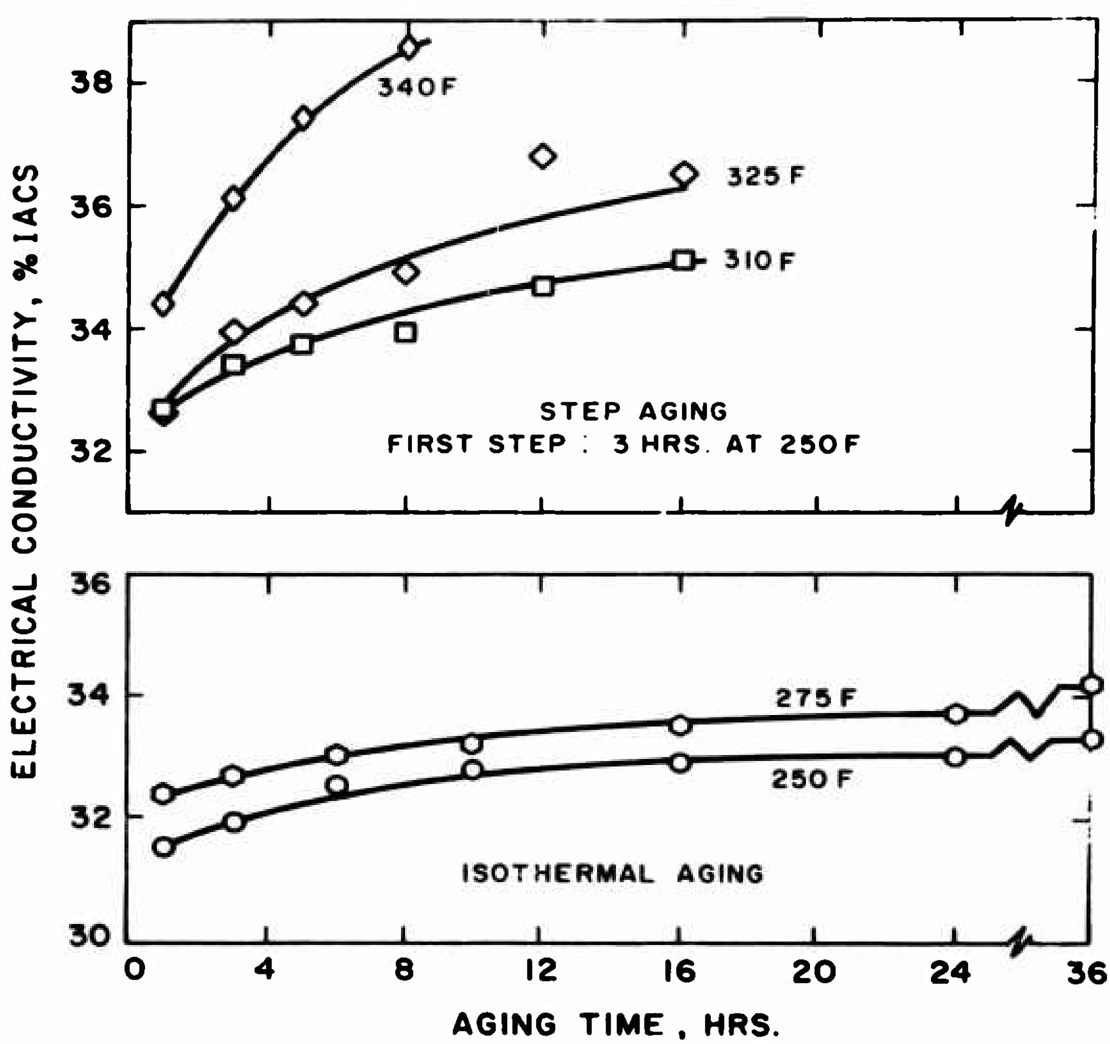


FIG. 7

Precipitation Treatment Curves - Electrical Conductivity vs Aging Time for .063 inch MA07-T6 Sheet.

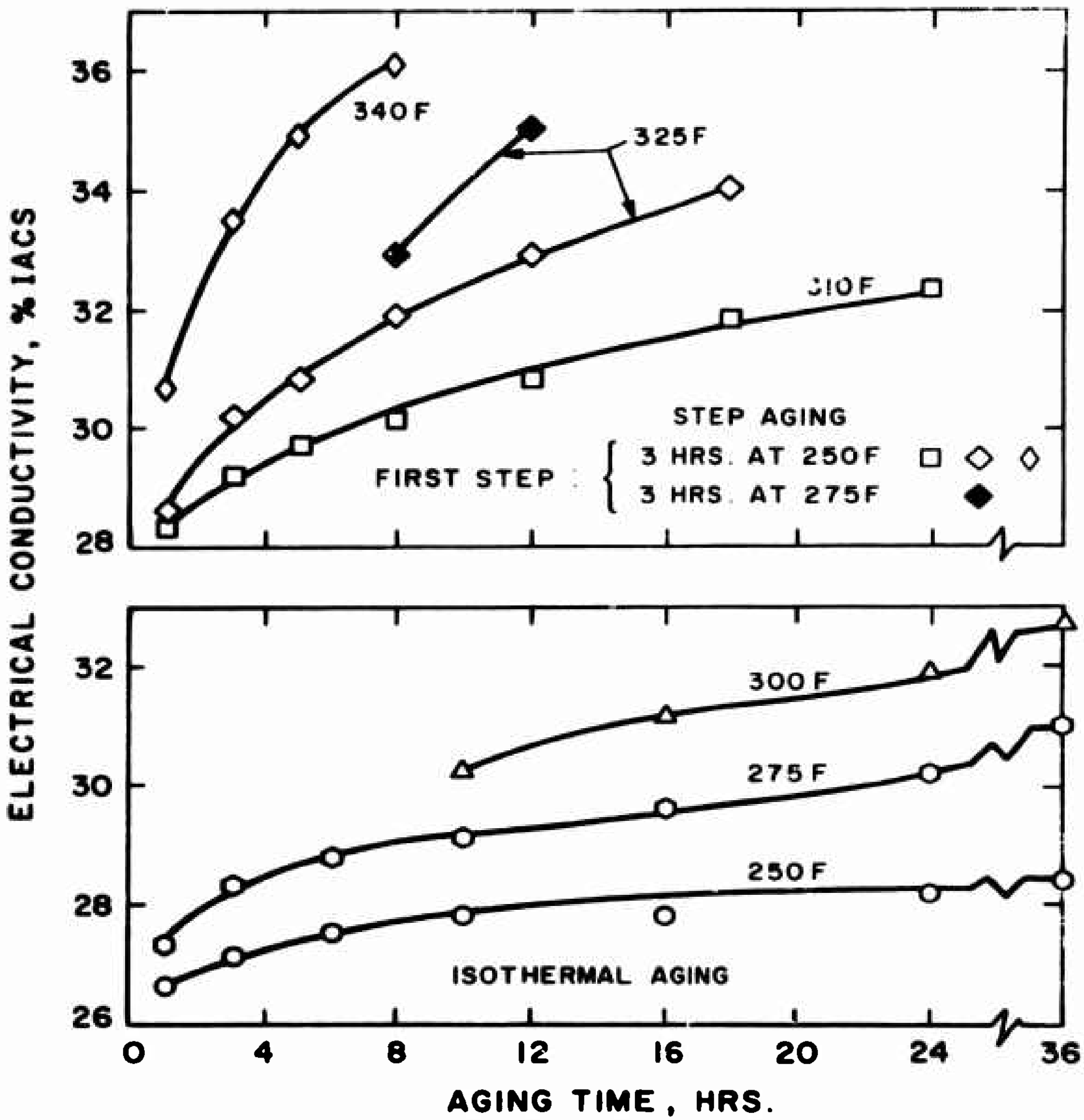


FIG. 8

Precipitation Treatment Curves - Electrical Conductivity vs Aging Time for .063 inch MA08-T6 Sheet.

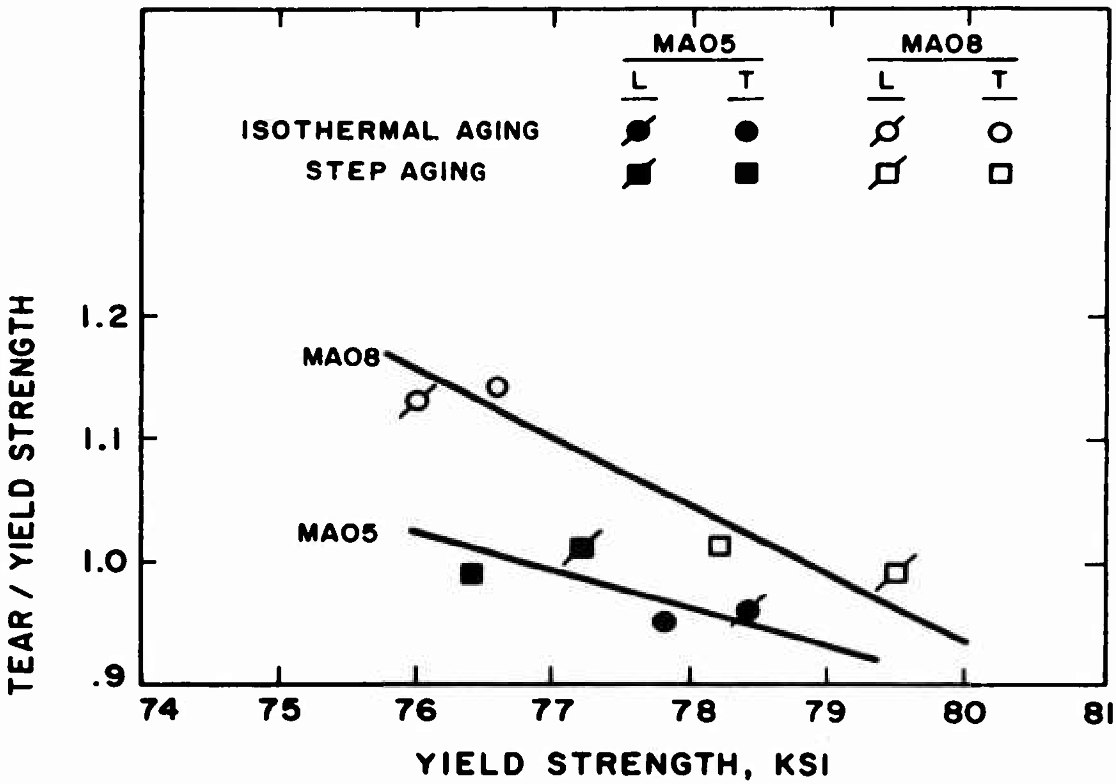


FIG. 9

Tear/Yield Strength Ratio vs Yield Strength for Isothermal and Step Precipitation Treated .063 inch MA05-T6 and MA08-T6 Sheet in Longitudinal and Transverse Directions.

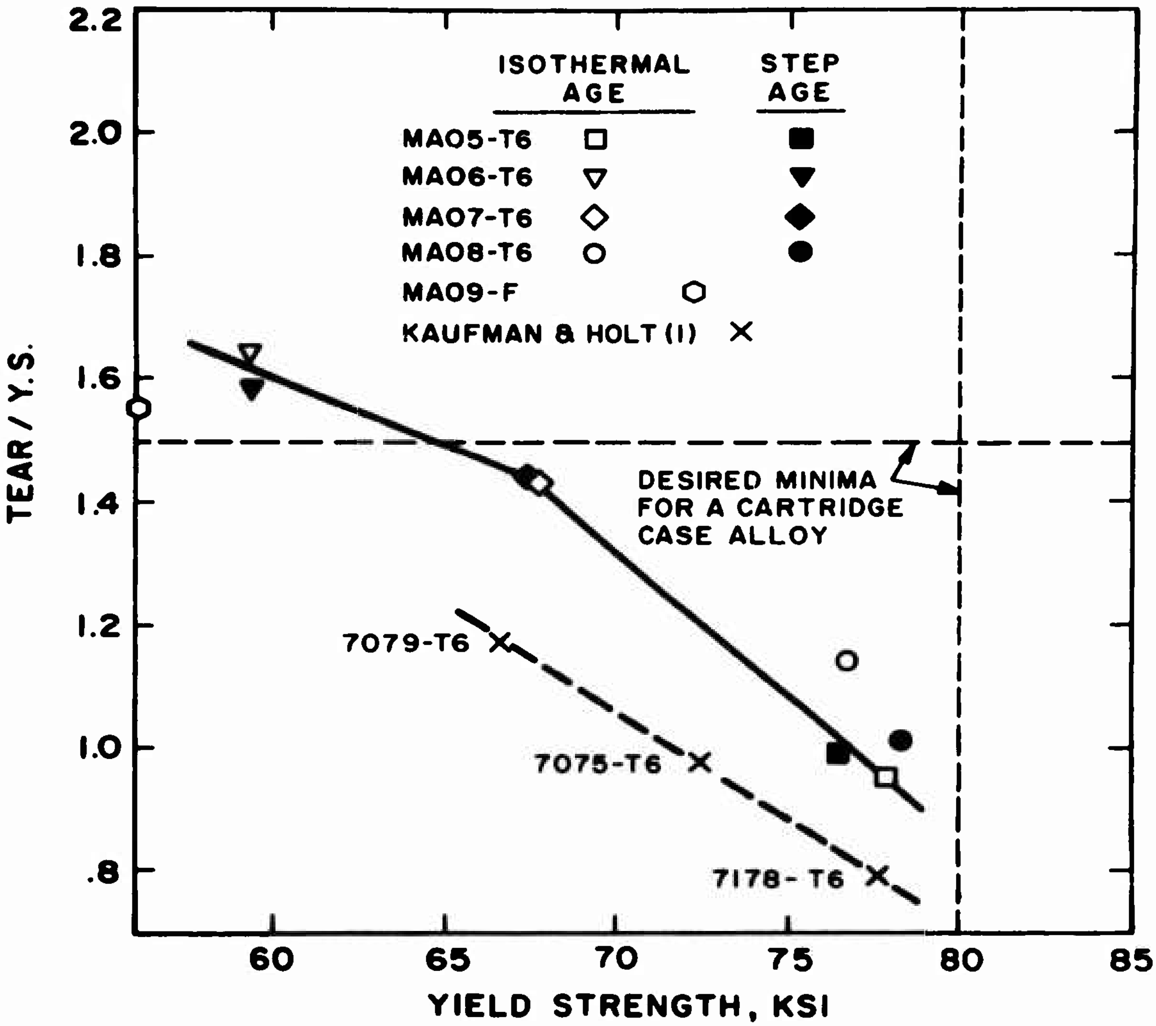


FIG. 10

Tear/Yield Strength Ratio vs Yield Strength in Transverse Direction for .063 inch MA05, MA06, MA07, MA08 and MA09 Sheet. Kaufman and Holt data are for same thickness and direction of test in commercial sheet.

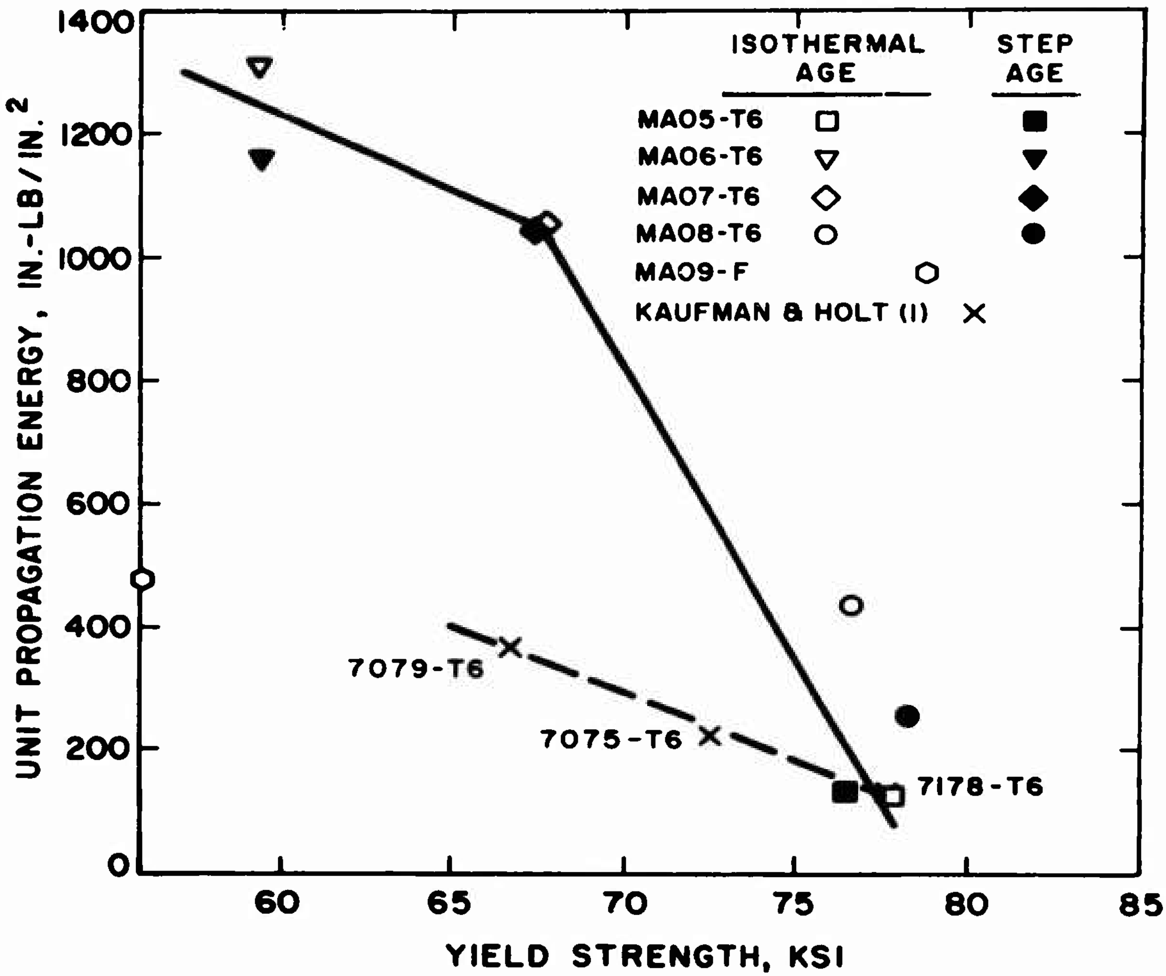


FIG. 11

Unit Propagation Energy vs Yield Strength in Transverse Direction for .063 inch MA05, MA06, MA07, MA08 and MA09 Sheet. Kaufman and Holt data are for same thickness and direction of test in commercial sheet.

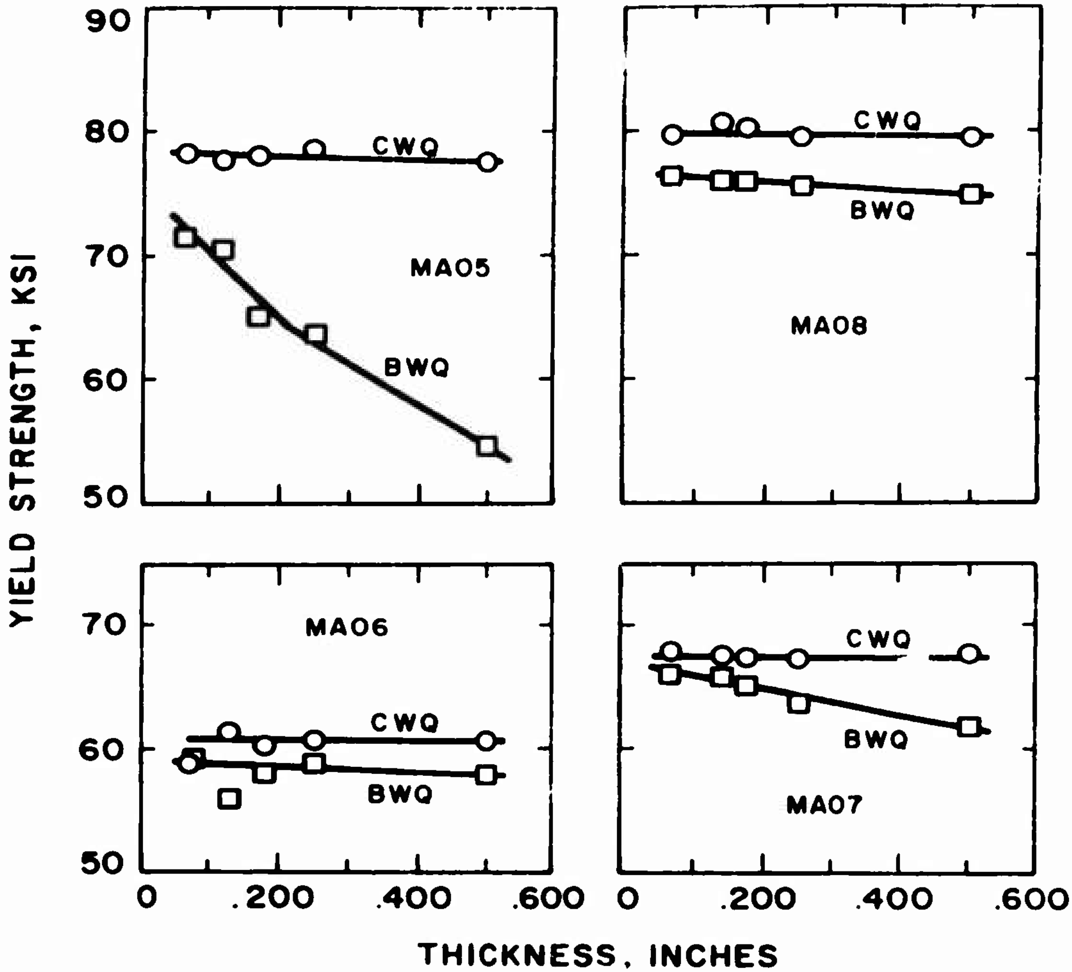


FIG. 12

Yield Strength vs Specimen Thickness for MA05, MA06, MA07 and MA08 Sheet or Plate after Quenching into Cold or Boiling Water and Subsequent Precipitation Treatments by Step Aging.

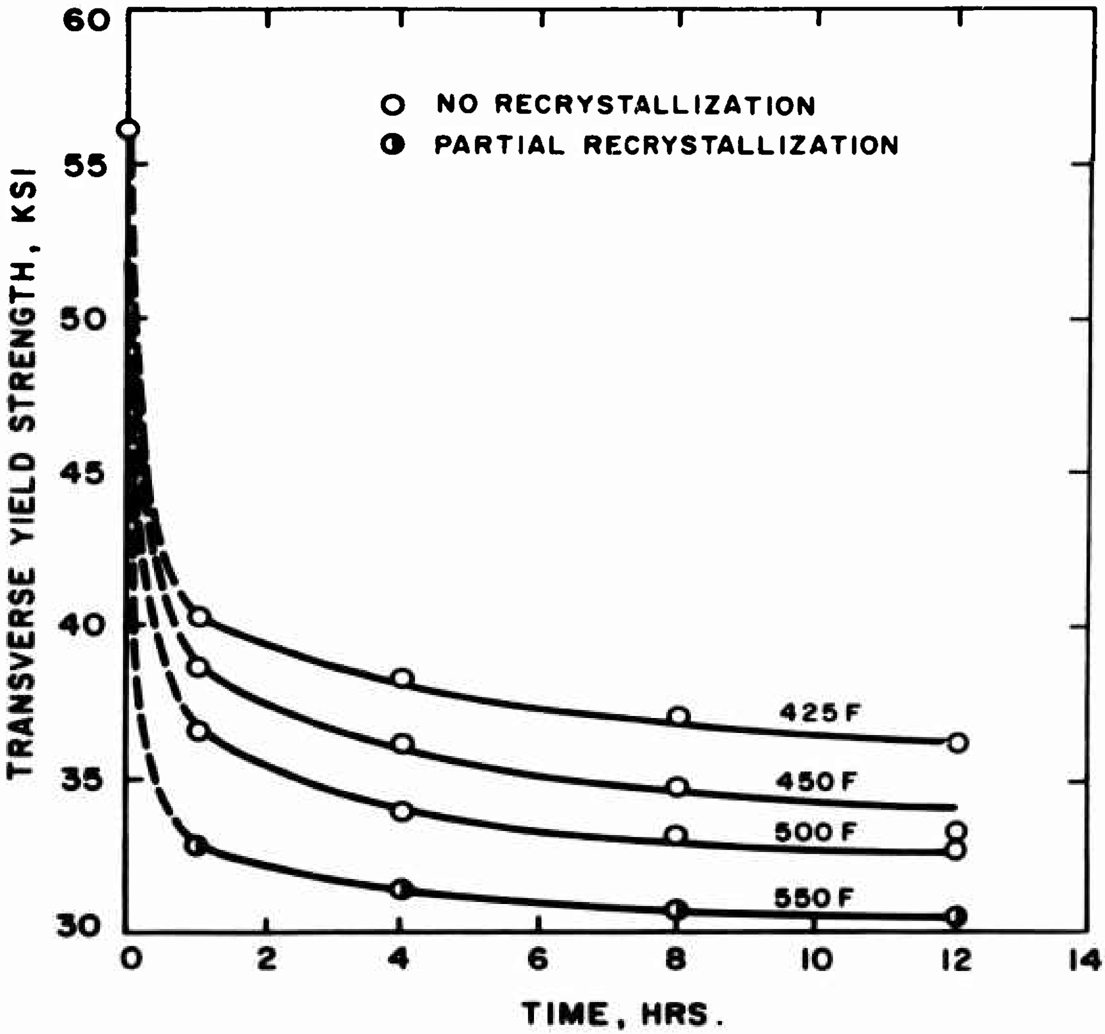
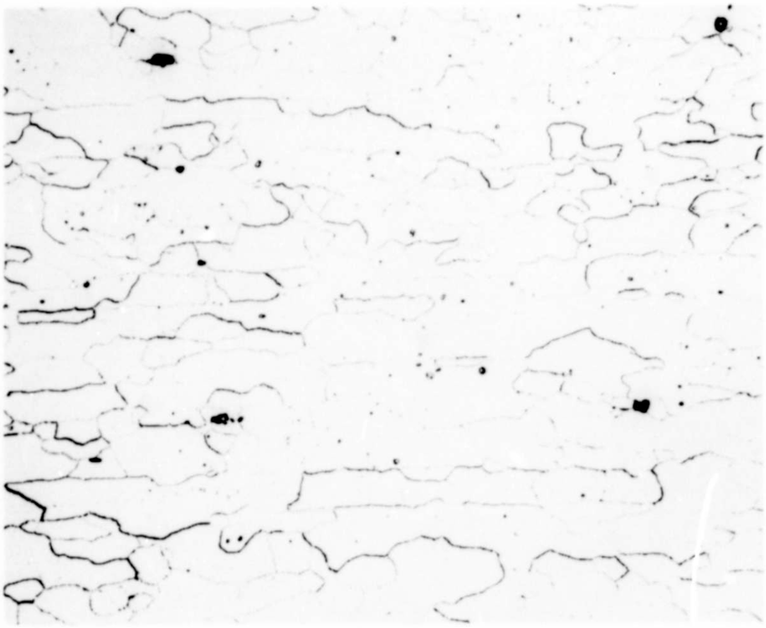


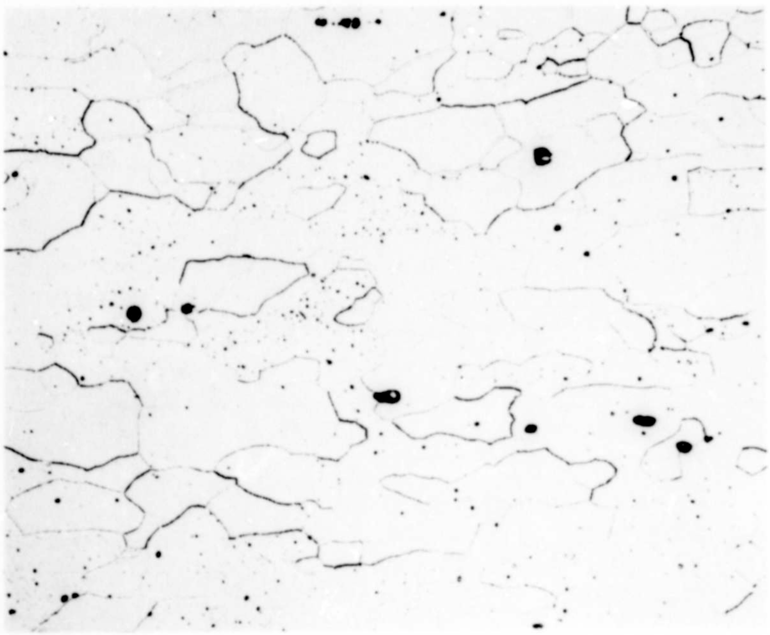
FIG. 13

Yield Strength and Degree of Recrystallization vs Time at Temperature for Thermal Stress Relief Treatments of .063 inch MA09-F Sheet.



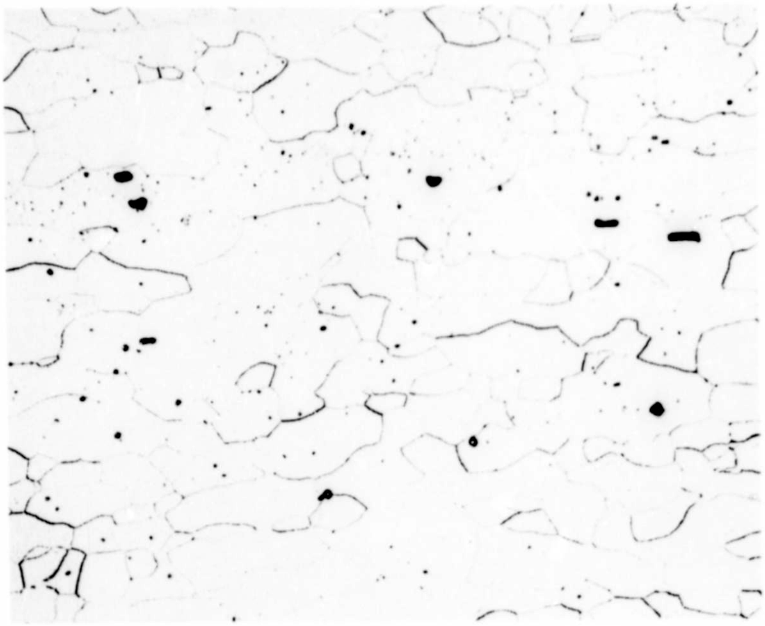
S-362033-6 Keller's Etch 500X

Fig. 14 - Microstructure of .063" MA05; solution heat treatment 1 hr at 890 F, precipitation treatment 24 hr at 275 F. Longitudinal section.



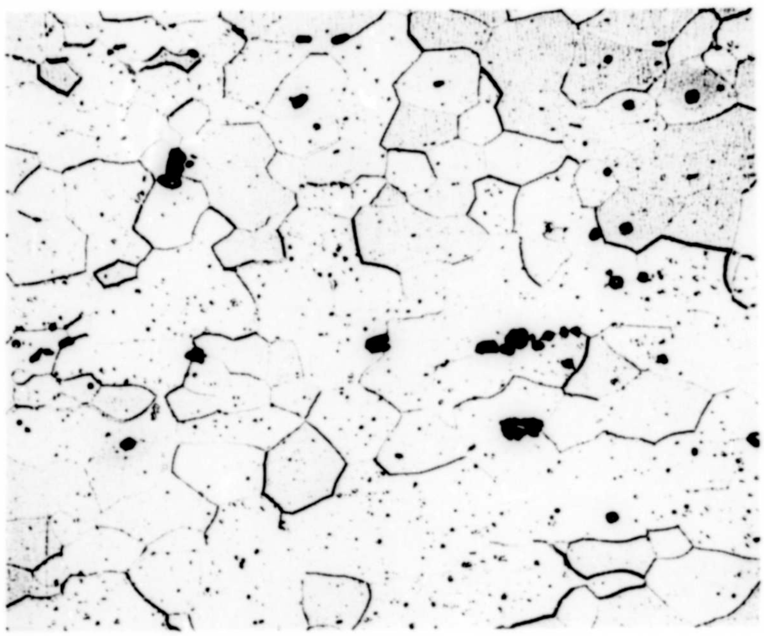
S-362034-6 Keller's Etch 500X

Fig. 15 - Microstructure of .063" MA06; solution heat treatment 1 hr at 960 F, precipitation treatment 24 hr at 275 F. Longitudinal section.



S-362035-6 Keller's Etch 500X

Fig. 16 - Microstructure of .063" MA07; solution heat treatment 1 hr at 960 F, precipitation treatment 24 hr at 275 F. Longitudinal section.

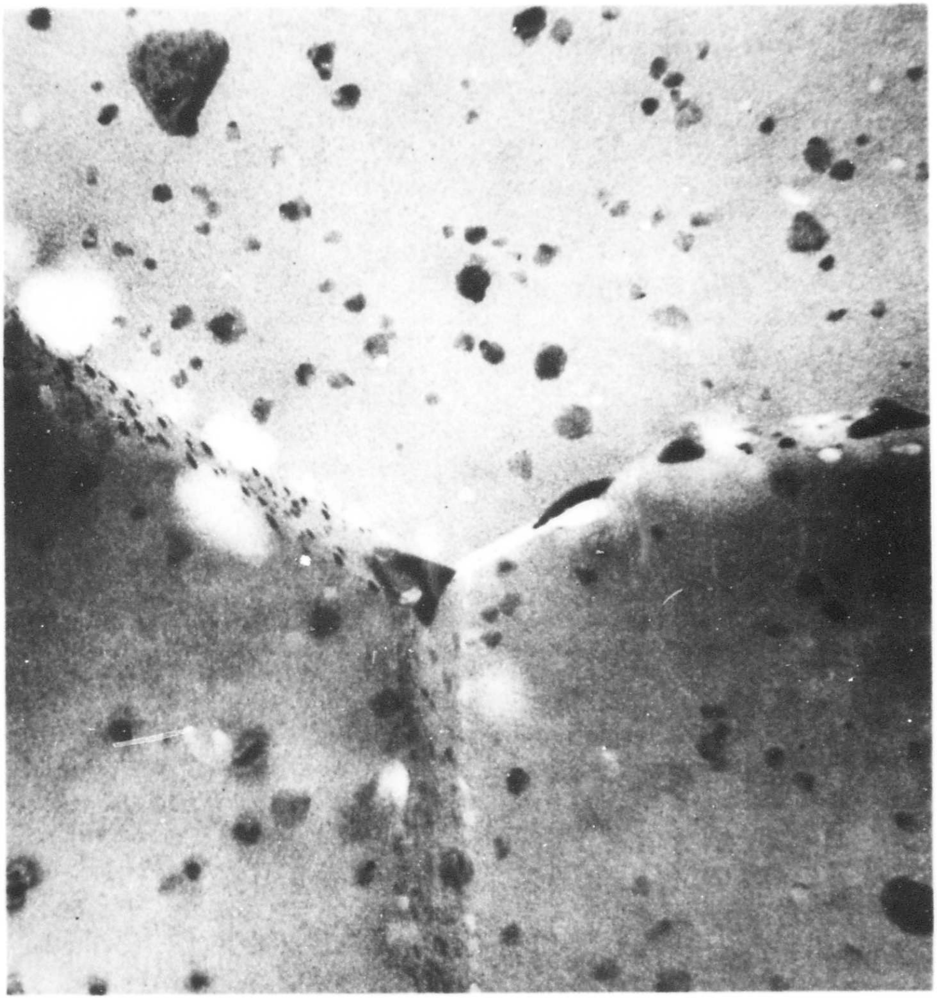


S-362036-6 Keller's Etch 500X

Fig. 17 - Microstructure of .063" MA08; solution heat treatment 1 hr at 910 F, precipitation treatment 36 hr at 275 F. Longitudinal section.

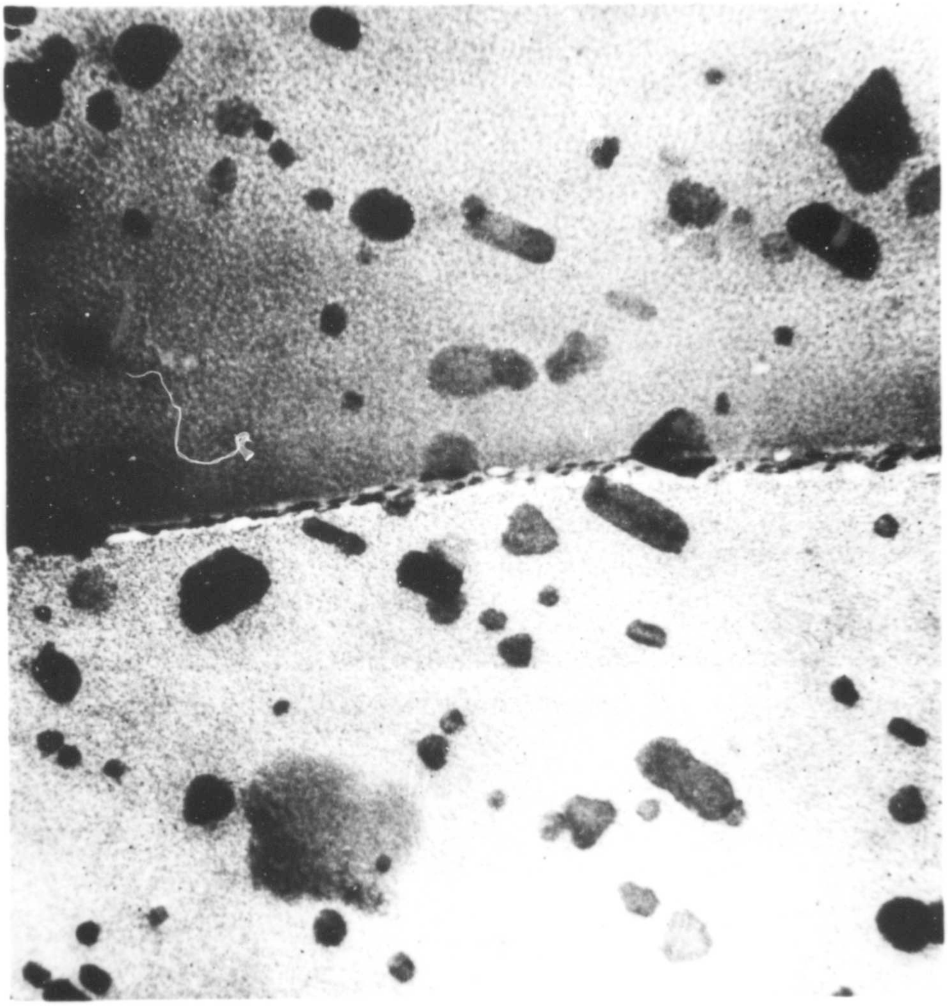
S-362037-3 Keller's Etch 500X

Fig. 18 - Microstructure of .063" MA09-F as-rolled sheet. Longitudinal section.



S-362033-6 50,000X

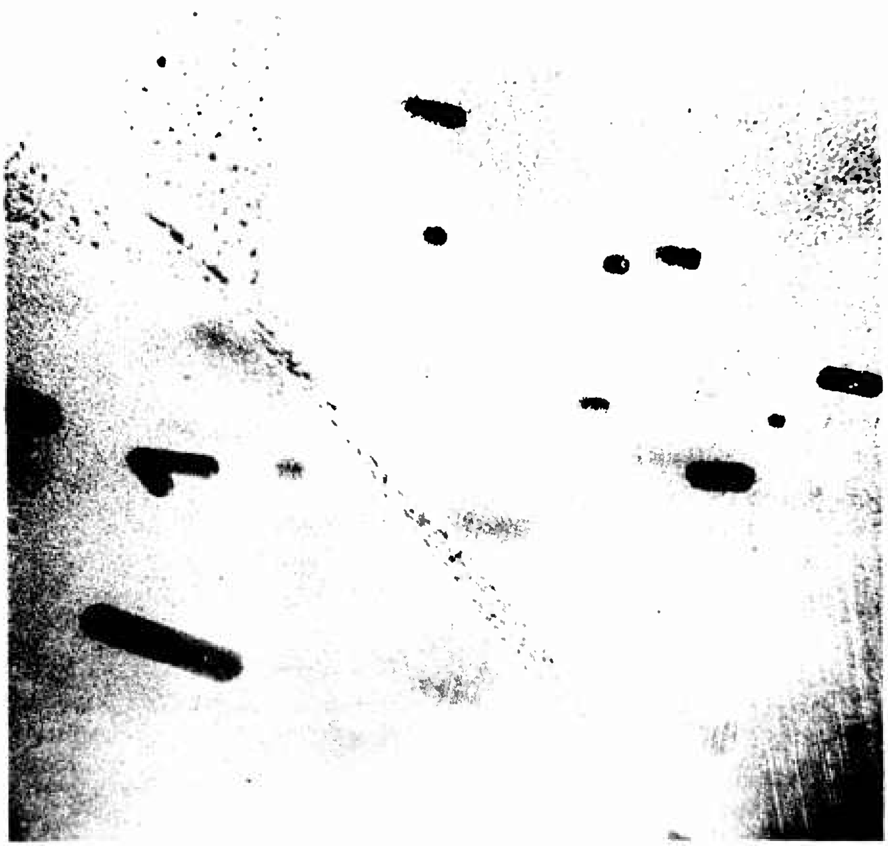
Fig. 19 - Electron micrograph of MA05. Solution heat treatment 1 hr at 890 F, precipitation treatment 24 hr at 275 F. Dispersoid particles within grains are E phase.



S-362034-ι 50,000X

Fig. 20 - Electron micrograph of MA06. Solution heat treatment 1 hr at 960 F, precipitation treatment 24 hr at 275 F. E phase particles are larger and less numerous than for MA05 in Figure 19.

Fig. 21 - Electron micrograph of MA07. Solution heat treatment 1 hr at 960 F, precipitation treatment 24 hr at 275 F. E phase particles similar in size to those in MA06, Figure 20.



S-362036-6 50,000X

Fig. 22 - Electron micrograph of MA08. Solution heat treatment 1 hr at 910 F, precipitation treatment 36 hr at 275 F. Dispersoid particles within grains are $Al_{20}Cu_2Mn_3$.

Zone Size

Range: 15–50 Å

Average: 25 Å

S-362033-6 (a) 100,000X

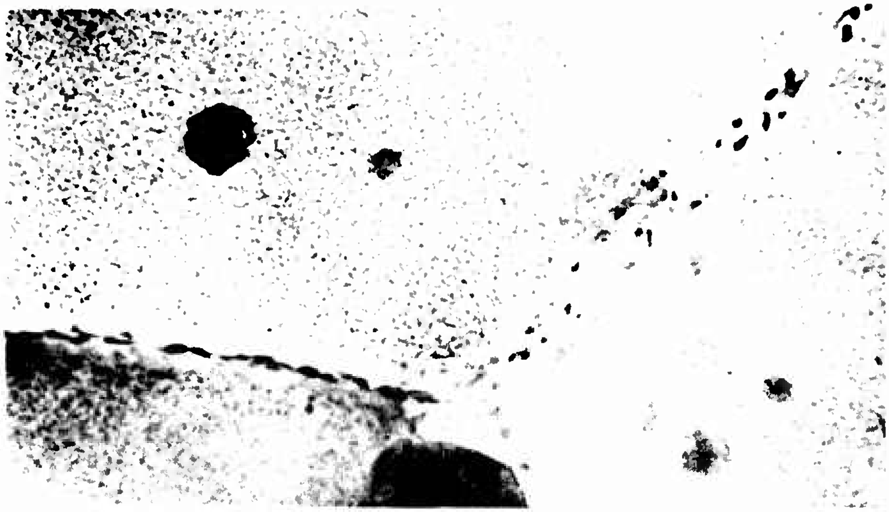
Zone Size

Range: 15–60 Å

Average: 40 Å

S-362033-9 (b) 100,000X

Fig. 23 - Electron micrographs of MA05. Solution heat treatment 1 hr at 890 F, precipitation treatment (a) 24 hr at 275 F, (b) 3 hr at 250 F plus 5 hr at 325 F.

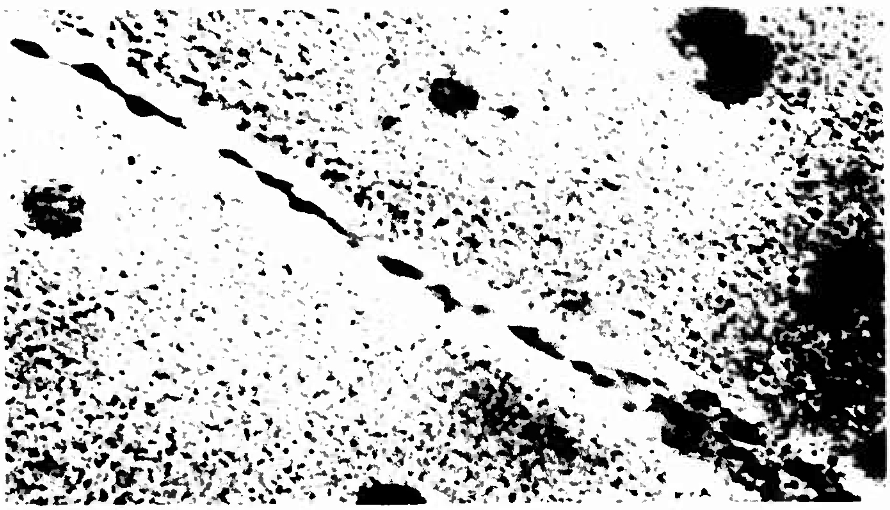


Zone Size

Range: 15-90 Å

Average: 50 Å

S-362034-6 (a) 100,000X



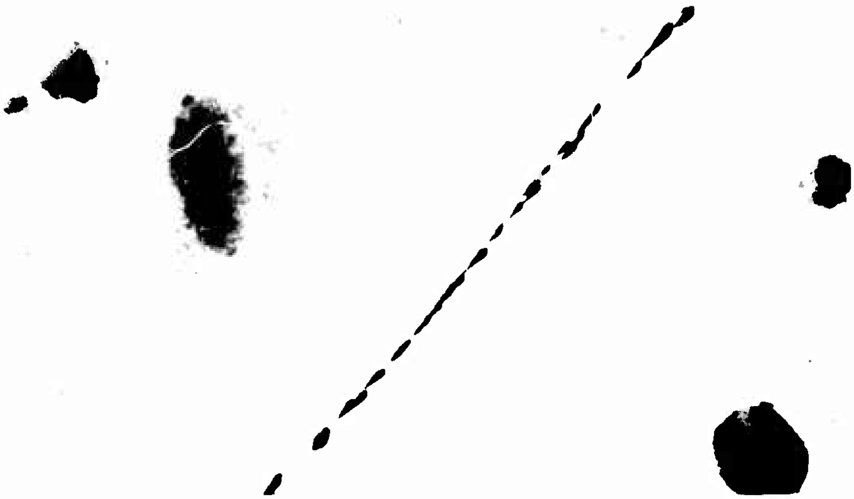
Zone Size

Range: 20-100 Å

Average: 60 Å

S-362034-3 (b) 100,000X

Fig. 24 - Electron micrographs of MA06. Solution heat treatment 1 hr at 960 F, precipitation treatment (a) 24 hr at 275 F, (b) 3 hr at 250 F plus 5 hr at 340 F.

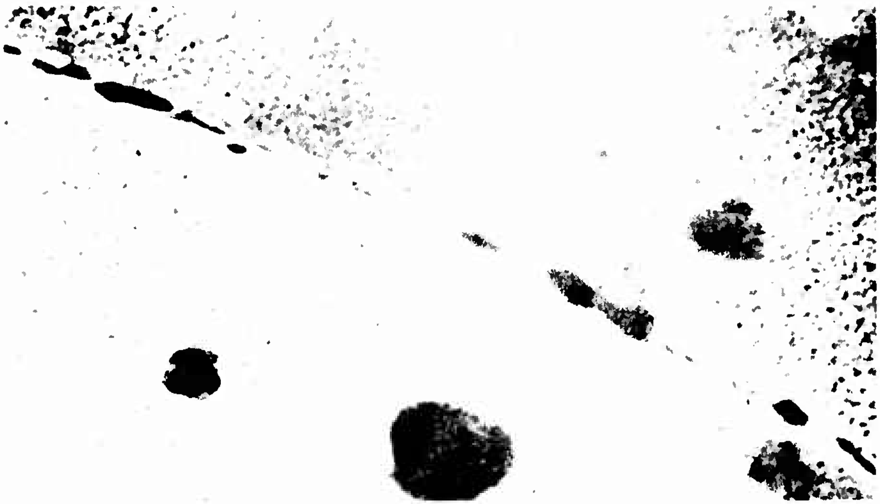


Zone Size

Range:
20-50 Å

Average: 30 Å

S-362035-6 (a) 100,000X



Zone Size

Range:
20-100 Å

Average: 60 Å

S-362035-3 (b) 100,000X

Fig. 25 - Electron micrographs of MA07. Solution heat treatment 1 hr at 960 F, precipitation treatment (a) 24 hr at 275 F, (b) 3 hr at 250 F plus 5 hr at 340 F.

Zone Size

Range: 10-50 Å

Average: 25 Å

S-362036-6 (a) 100,000X

Zone Size

Range: 15-90 Å

Average: 50 Å

S-362036-9 (b) 100,000X

Fig. 26 - Electron micrographs of MA08. Solution heat treatment 1 hr at 910 F, precipitation treatment (a) 36 hr at 275 F, (b) 3 hr at 250 F plus 9 hr at 325 F.

S-362033-6 (a) 570X

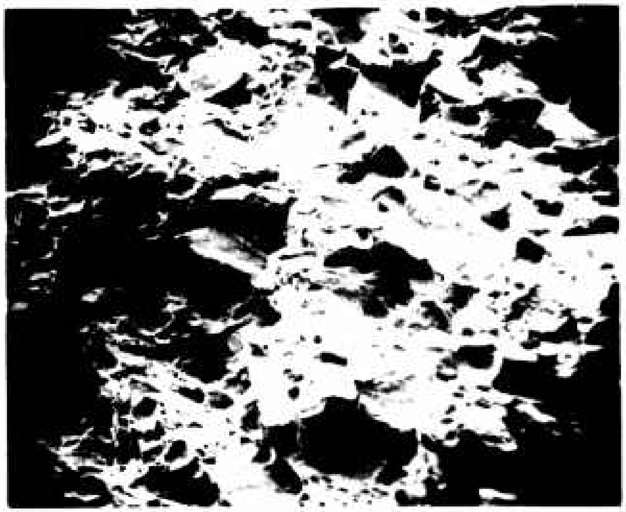
S-362033-6 (b) 2900X

Fig. 27 - Scanning electron microscope fractograph of MA05-T6 tear specimen fracture of low U.P.E.

S-362035-6 (a) 480X

S-362035-6 (b) 1900X

Fig. 28 - Scanning electron microscope fractograph of MA07-T6 tear specimen fracture of high U.P.E.



S-362036-6 570X

Fig. 29 - Scanning electron microscope fractograph of MA08-T6 tear specimen fracture of intermediate U.P.E.

S-362033-6 12,000X

Fig. 30 - Transmission electron micrograph of oxide replica of fracture surface from MA05-T6 tear specimen of low U.P.E.

S-362035-6 12,000X

Fig. 31 - Transmission electron micrograph of oxide replica of fracture surface from MA07-T6 tear specimen of high U.P.E.

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4 DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final Report for Period 6/28/68 to 10/28/69

5 AUTHOR(S) (Last name, first name, initial)

Rogers, Ralph. W., Jr.

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13 ABSTRACT

Five experimental, low impurity content aluminum alloys were evaluated for characteristics such as tensile properties, fracture toughness, resistance to corrosion and stress corrosion, temperature stability and quench sensitivity.

Although none of the alloys achieved the target strength-toughness criteria, two compositions were superior to conventional alloys in this respect. These were nominally Al-5 Zn-2.4 Mg-1.2 Cu-.15 Cr (MA07) and Al-5.9 Zn-2.4 Cu-2.2 Mg-.3 Mn (MA08).

One strain-hardenable alloy, Al-7.5 Mg-.1 Mn-.1 Cr (MA09) was included in the evaluation and displayed good notch toughness and moderate resistance to crack growth but at a relatively low strength level compared to the heat-treatable alloys.

Electron metallography and fractography showed fracture toughness to depend upon the relative proportions of fracture path that were intergranular or transgranular and, hence, upon relative strengths of grain interiors and boundaries. The effect of second-phase constituent particles upon fracture toughness was not discernible at the low insoluble element level of these alloys.

DD FORM 1 JAN 64 1473

Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Aluminum Alloys Experimental Alloys Alternate Materials for Ctg. Cases.						

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There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. **KEY WORDS:** Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.